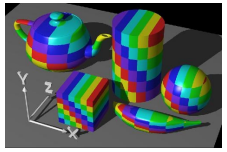
CS770/870 Spring 2017 Texture Mapping



Related material

Cunningham: Ch. 9
Angel 5e: 8.6-8.8, 8.10
Angel 6e: 7.4-7.10
Hill and Kelley: Ch. 8.5

Heckbert, Survey of Texture Mapping, *IEEE Computer Graphics and Applications*, Nov. 1986.
Heckbert and Moreton, Interpolation for Polygon Texture Mapping and Shading, *State of the Art in Computer Graphics: Visualization and Modeling*, Springer-Verlag, 1991
Rosalee Wolfe, Teaching Texture Mapping Visually, Google: Siggraph Texture Tutorial

Preview

- 2D textures
  - mapped onto 3D surfaces
    - polygons
    - polygon meshes
    - curved surfaces
  - indirect mapping
  - direct mapping
  - incorporating into scan conversion
    - linear interpolation
    - rational linear interpolation
- 3D textures
- Bump mapping
- Displacement mapping

2D Texture mapping

- Most real surfaces have patterns/textures
- Inefficient to model a textured surface as many hundreds or thousands of very small triangles
- Instead, *map* a texture onto surface if visible
- Texture usually defined as *pixmap*, whose elements are called *texels*
- Need mapping of texture space to surface
- For each image pixel covered by an object, find texture pixel(s), *texels*, that map to it
- But that means we need a mapping of the texture space to the object's surface

Texture Mapping Overview

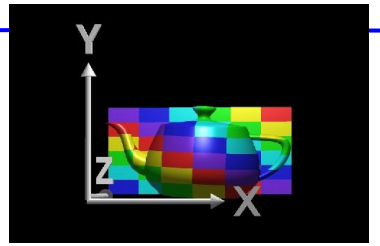
- Conceptually, we *map* a *texture* to a *surface*
  - want to do mapping in the context of filling pixels
  - Surface + texture must map to pixels
  - So, map:T $\Rightarrow$ S is a transformation specification
- Classes of mappings
  - indirect mapping via an intermediary surface
    - map texture space to a simpler object and then map the surfaces of that object to the real object
  - direct mappings
    - parametric surface representation
    - 2D coordinate frame transformation

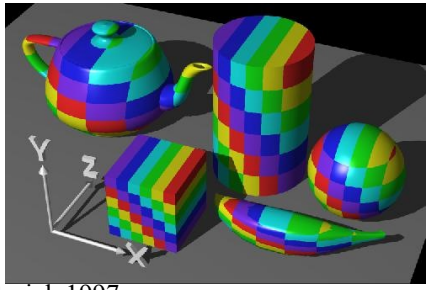
Indirect Mapping
Using an Intermediary Surface

- Can sometimes get a useful, inexpensive result by mapping the texture to a simple surface and then mapping that to the object
  - Plane normal to a principal axis
  - bounding cylinder
  - bounding sphere
  - bounding box
- The surface is called the *map shape*
- There various ways to map from the object to the shape

Mapping via a Principal Plane

- Map texture (r,s) to object (x,y), usually with scale
  - usually define texture space as going from (0,0) to (1,1)
  - scale that to just cover the extent of object in *xy* or *yz* or *xz*
  - for each visible point on object surface, easy to select the *(r,s)* color, where $r=x$ and $s=y$ (if using *xy* plane)

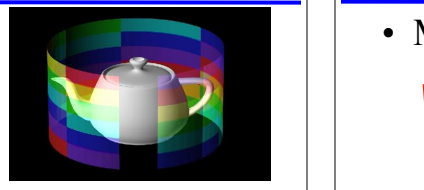


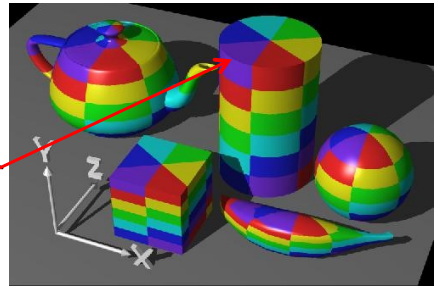


Images from R. Wolfe, Siggraph Tutorial, 1997

Mapping via a Cylinder

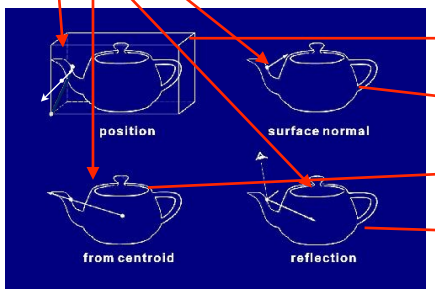
- Easy to wrap texture around a cylinder and map that to object
  - Cylinder is rolled up rectangle
  - map image *s* to cylinder *y*
  - map image *r* to cylinder ϕ
  - can project object's visible *x,y* position onto cylinder
- Cylinder top and bottom
  - can have "own" texture
  - can "extend" top/bottom edge of side texture along edge to center

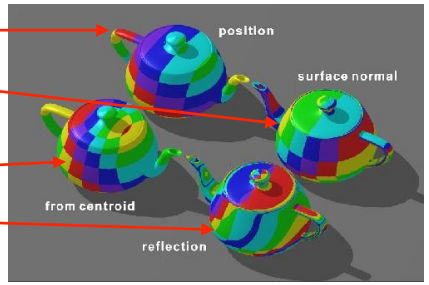




Mapping from Object to Map Shape

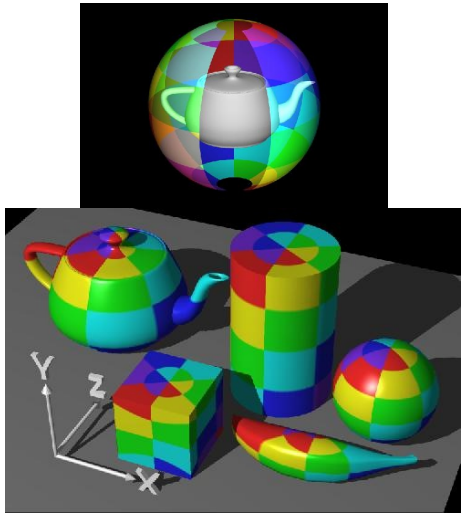
- Many ways to map point on object to the map shape
  - position: visible point's position mapped to shape (projection)
    - Using coord system of map shape (cylindrical, spherical, or Cartesion)
  - surface normal from visible point to shape
  - centroid to visible point to shape
  - principal reflection direction of visible point wrt to viewer





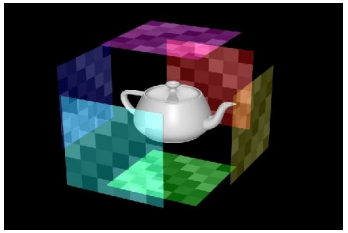
Mapping via a Sphere

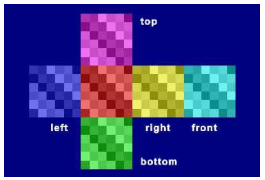
- Except for poles, mapping to a sphere, then object is pretty easy
  - could wrap cylinder around sphere, map to sphere, then to object
  - but, it's not hard to map directly to sphere, then to object

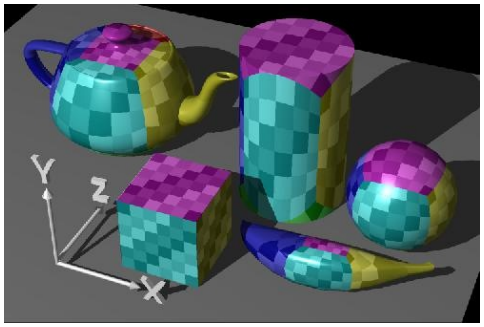


Mapping via a Bounding Box

- Using a box as the intermediary requires a more complex texture, but mapping is still easy

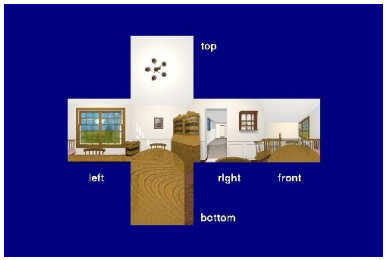






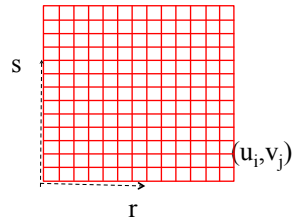
Environment Mapping

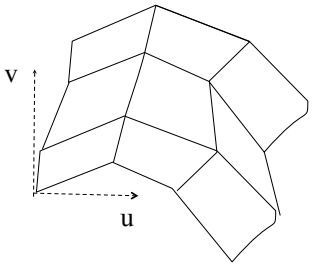
- When the textures on the box represent a "photo" of the environment in each direction, it's called an <u>environment mapping</u> or <u>reflection mapping</u>.



Parametric Surface Representation

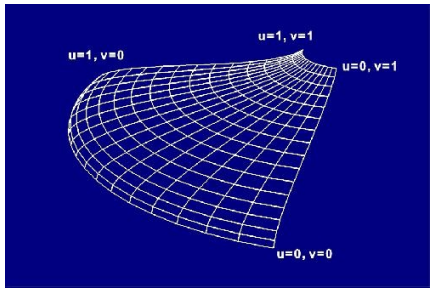
- Easy to define 2d parametric texel coordinates, (r, s)
- Not so easy to define a parametric representation for every polygon; same continuity problem
- If a parametric curved surface generated a polygonal mesh, can save the parametric variables at each mesh point, (u_i, v_j)

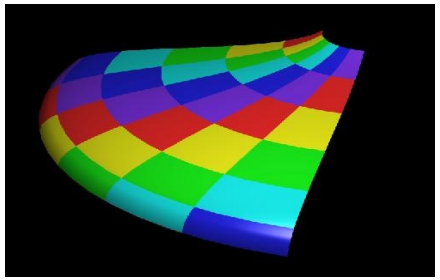




Parametric Mapping Example

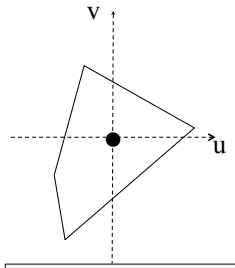
- Given mesh generated from a surface, can just store parametric values for the surface points with each mesh point, then look up texel value for visible pixels.





2D Coordinate Frame Mapping

- Coordinate frame transform needs
  - a texture coordinate system
    - easy to derive from the texel index coordinates (2D array)
  - a coordinate system defined on each polygon face
    - tedious for scene designer
    - heuristic algorithm might work:
      - origin is geometric center
      - face *v*-axis is projection of object coordinate y onto plane, if it exists, and face *u*-axis is orthogonal to face y, such that uvn (outward normal) is RHS
    - But, what about neighboring faces? How will texture mapping change at boundaries?



Might be ok if have only a few large faces with no continuity needed across them

Coordinate System Issues

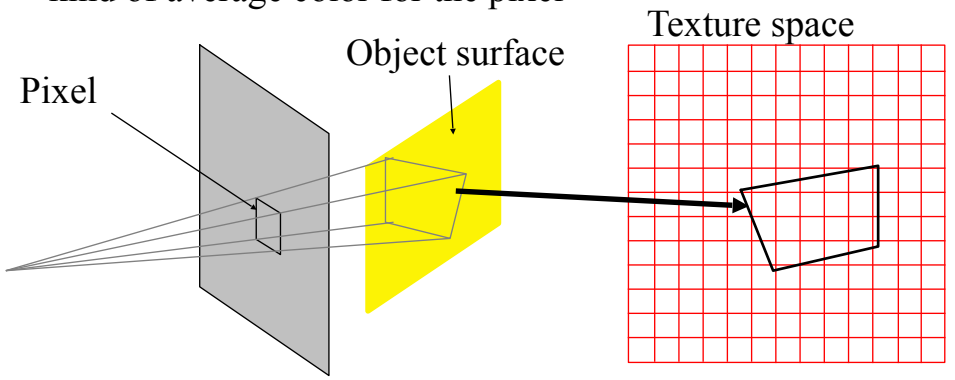
- Object is defined in its own coordinate system, OC
- OC are mapped to world coordinates, WC
- WC are mapped to eye coordinates EC
- EC are mapped to normalized projection coords, NPC
- NPC are mapped to screen coordinates, SC

Where is texture mapping done?

  – For performance reasons it should be done in screen coordinates – that's the only way to avoid excessive calculations.

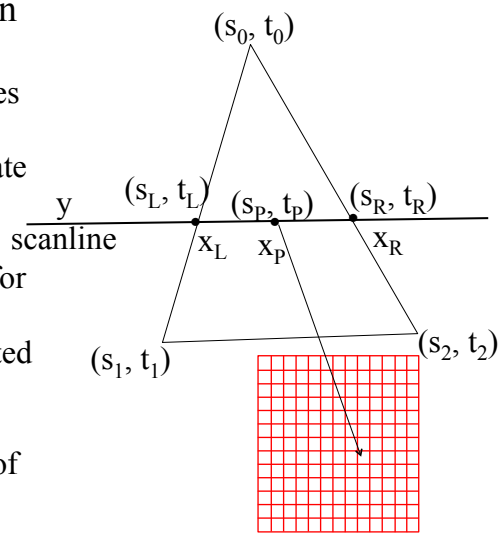
Pixel-based Mapping

Map pixel to object surface, then to texture space
If image of pixel covers multiple *texels*, take some kind of average color for the pixel



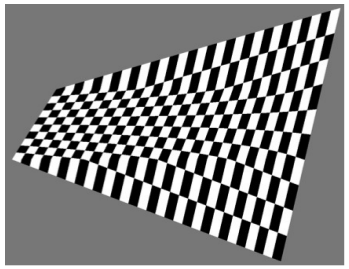
Texture Mapping During Scan Conversion

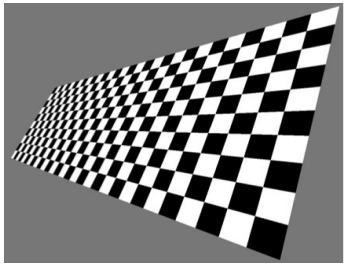
- Render texture during scan conversion
  - Compute texture coordinates at vertices
  - For each scanline, interpolate coordinates along polygon edges
  - Interpolate along scanline for each pixel
  - At each pixel use interpolated texture coords to look up color in texture map
- Need more work to find area of pixel in texture



Perspective Transformation Problem

- Linear interpolation fails with perspective projection
  - polygon faces are *foreshortened*; *z* values along projected plane are not linear in screen space





- Elegant solution: Heckbert and Moreton (UNH CS grad)

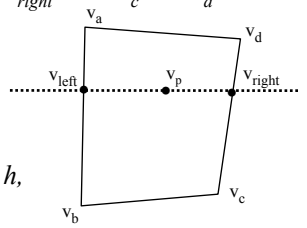
Images from Heckbert and Moreton, 1991

Rational Linear Interpolation

- Heckbert and Moreton's approach:
  - Given a set of vertex *parameters* in object space, p_i, $i=1 \ldots n$
    - map vertex $(ox, oy, oz, 1)$ to 3D screen space to get (wx, wy, wz, w)
    - clip against frustum, linearly interpolate all 4 vertex coords as needed
    - divide ***all*** parameters and coordinates by w to get:
      $s_i = p_i/w$, $i=1 \ldots n$ and $(x, y, z, 1)$
    - add a new parameter, $s_{n+1} = 1/w$
    - apply linear interpolation to all of $(x, y, z, s_1, s_2, \ldots, s_n, s_{n+1})$ throughout scan conversion algorithm.
    - at each pixel, compute $r_i = s_i / s_{n+1}$ for $i = 1, \ldots, n$
  - Key idea:
    - Do linear interpolation of *normalized* parameters and the homogeneous normalization factor, $1/w$
    - Correct parameter is the interpolated *normalized* parameter $(s_1, s_2, \ldots, s_n)$ **divided by** interpolated *normalization* factor, s_{n+1}.

Scan Conversion Parameters

- Identify parameters such as texture coords, color etc.
- Interpolate these parameters divided by the homogeneous coord
  - Texture coordinates (u,v), divided by w, which is (u/w, v/w)
  - Vertex colors (r,g,b), divided by w (r/w, g/w, b/w)
  - Vertex normals divided by w: $(n_x/w, n_y/w, n_z/w)$
  - **plus** the homogeneous normalization factor (h=1/w)
- For each (new) parameter value, v (including h)
  - Interpolate v along edges: get v_{left} from v_a and v_b and v_{right} from v_c and v_d
  - Interpolate parameters between edges across scanline: get v_p from v_{left} and v_{right}.
  - For each pixel, p, and each parameter, v_p
    $v'_p = v_p / h_p = v_p / (1/w_p) = v_p * w_p$
  - So, by interpolating u/w and h and dividing result by h, the homogeneous factor is canceled at the end.



Bump Mapping

- Texture maps can also be used to perturb the surface normal at a pixel before lighting model applied
  - Texture map interpreted as an intensity field (1 variate)
    - At texel[i,j], compute approximation to the gradient at that point
      dy = texel[i+1, j] - texel[i, j]
      dx = texel[i, j+1] - texel[i, j]
    - If the surface normal is N = (N_x , N_y , N_z)
      let N'= (N_x + dx, N_y + dy, N_z)
    - Perturbs normal at each pixel differently according to the texture values
- Use color texture map to directly store the perturbation: (r, g, b) ⇒ (dx, dy, dz)
- Normal maps use the rgb to store the normal itself

Displacement Mapping

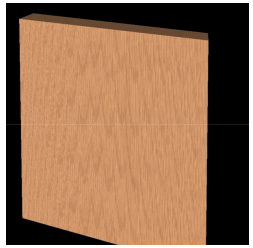
- Bump mapping gives the appearance of a bumpy surface without creating one; this is easily seen in the smooth silhouette
- Displacement mapping changes the *geometry* of the surface by moving vertex positions by a displacement determined from a texture map.
  - some techniques can insert new vertices (tessellate an existing triangle) to get higher resolution surface structure
  - provides correct silhouettes and visibility
  - harder to get correct shadows from the displacements
- Related: parallax mapping, relief mapping

3D Textures

- Defined by
  - a volume data set; a 3D array of *voxels*, or
  - a procedural specification that computes 3D values as needed
- Texture values are accessed by 3 indices (or 3 parametric variables)
- A 3D volume (not just its faces) is mapped to the 3D texture space
  - the faces are rendered as usual, but the texture mapping uses the 3D object coordinates to map to 3D texture coordinates

3D Texture Mapping Characteristics

- Great for modeling wood, marble, stone, etc.
  - great continuity and consistency around corners
    - 3D texture mapping is equivalent to solid wood cabinets and solid countertops (granite, Corian, Ice Stone, etc.)
    - 2D texture mapping is equivalent to laminate cabinets and formica countertops
  - there are pretty good models for generating realistic solid representations of these surfaces
- Much more computation and/or memory needs compared with 2D texture mapping
  - volume data approach is especially expensive because of memory needs -- unless the texture is highly repeatable



Images from Senior thesis by Claurissa Tuttle, Univ of Utah