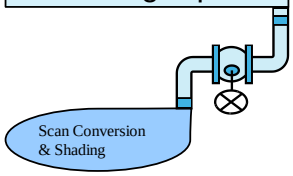
קורס גרפיקה ממוחשבת

סמסטר ב' 2008

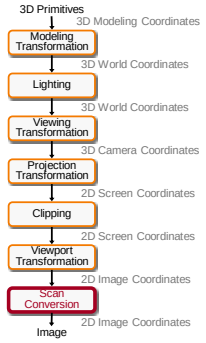
ליאור שפירא

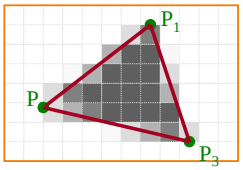
3D Polygon Rendering Pipeline



Thomas Funkhouser
Princeton University
C0S 426, Fall 1999

3D Rendering Pipeline (for direct illumination)





Scan Conversion
& Shading

Overview

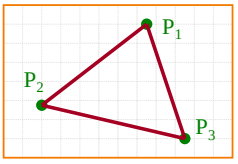
- Scan conversion
  - Figure out which pixels to fill
- Shading
  - Determine a color for each filled pixel
- Texture Mapping
  - Describe shading variation within polygon interiors
- Visible Surface Determination
  - Figure out which surface is front-most at every pixel

Scan Conversion

- Render an image of a geometric primitive by setting pixel colors

```
void SetPixel(int x, int y, Color rgba)
```

- Example: Filling the inside of a triangle



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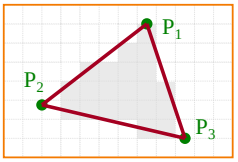
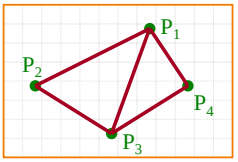


Triangle Scan Conversion

- Properties of a good algorithm
  - Symmetric
  - Straight edges
  - Antialiased edges
  - No cracks between adjacent primitives
  - MUST BE FAST!



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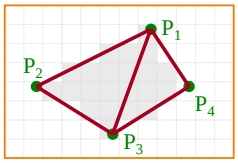
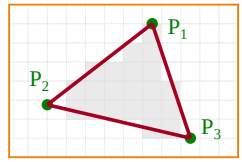


Simple Algorithm

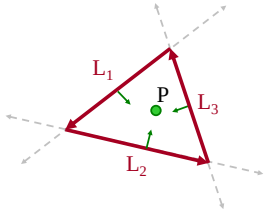
- Color all pixels inside triangle

```
void ScanTriangle(Triangle T, Color rgba){
  for each pixel P at (x,y){
     if (Inside(T, P))
        SetPixel(x, y, rgba);
  }
}
```



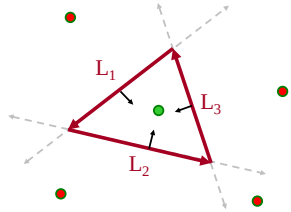
Inside Triangle Test

- A point is inside a triangle if it is in the positive halfspace of all three boundary lines
  - Triangle vertices are ordered counter-clockwise
  - Point must be on the left side of every boundary line



Inside Triangle Test

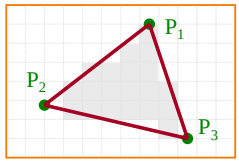
```
Boolean Inside(Triangle T, Point P)
{
  for each boundary line L of T {
     Scalar d = L.a*P.x + L.b*P.y + L.c;
     if (d < 0.0) return FALSE;
  }
  return TRUE;
}
```



Simple Algorithm

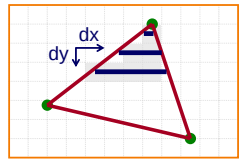
- What is bad about this algorithm?

```
void ScanTriangle(Triangle T, Color rgba){
  for each pixel P at (x,y){
     if (Inside(T, P))
        SetPixel(x, y, rgba);
  }
}
```



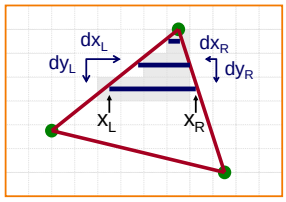
Triangle Sweep-Line Algorithm

- Take advantage of spatial coherence
  - Compute which pixels are inside using horizontal spans
  - Process horizontal spans in scan-line order
- Take advantage of edge linearity
  - Use edge slopes to update coordinates incrementally



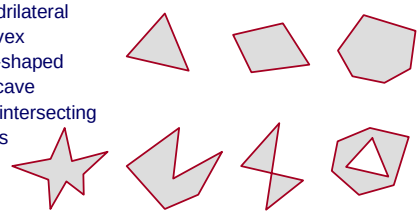
Triangle Sweep-Line Algorithm

```
void ScanTriangle(Triangle T, Color rgba){
  for each edge pair {
     initialize xL, xR;
     compute dxL/dyL and dxR/dyR;
     for each scanline at y
        for (int x = xL; x <= xR; x++)
           SetPixel(x, y, rgba);
     xL += dxL/dyL;
     xR += dxR/dyR;
  }
}
```



Polygon Scan Conversion

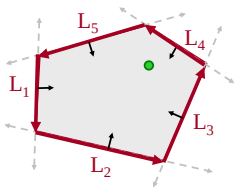
- Fill pixels inside a polygon
  - Triangle
  - Quadrilateral
  - Convex
  - Star-shaped
  - Concave
  - Self-intersecting
  - Holes



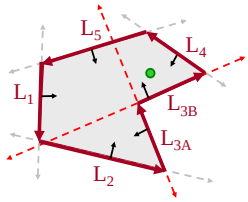
What problems do we encounter with arbitrary polygons?

Polygon Scan Conversion

- Need better test for points inside polygon
  - Triangle method works only for convex polygons



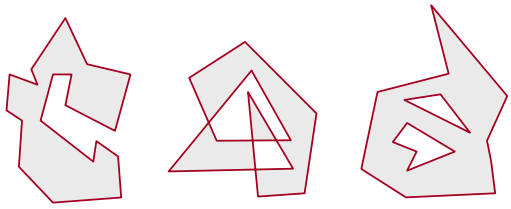
Convex Polygon



Concave Polygon

Inside Polygon Rule

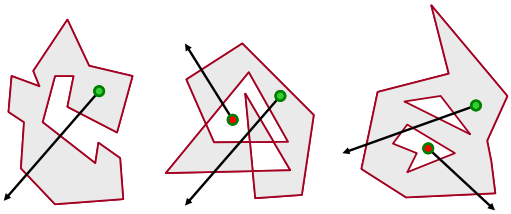
- What is a good rule for which pixels are inside?



Concave Self-Intersecting With Holes

Inside Polygon Rule

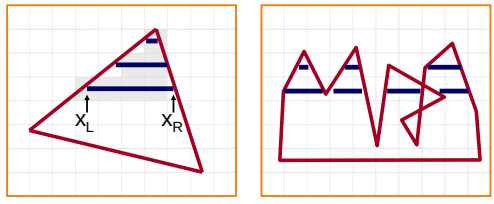
- Odd-parity rule
  - Any ray from P to infinity crosses odd number of edges



Concave Self-Intersecting With Holes

Polygon Sweep-Line Algorithm

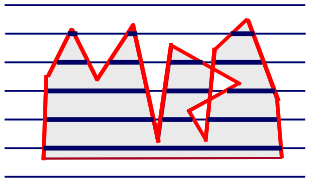
- Incremental algorithm to find spans, and determine insideness with odd parity rule
  - Takes advantage of scanline coherence



Triangle Polygon

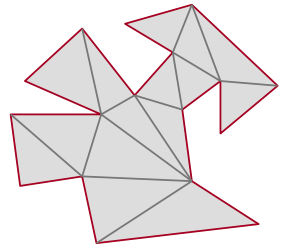
Polygon Sweep-Line Algorithm

```
void ScanPolygon(Triangle T, Color rgba){
   sort edges by maxy
   make empty "active edge list"
   for each scanline (top-to-bottom) {
      insert/remove edges from "active edge list"
      update x coordinate of every active edge
      sort active edges by x coordinate
      for each pair of active edges (left-to-right)
         SetPixels(x_i, x_i+1, y, rgba);
      }
}
```



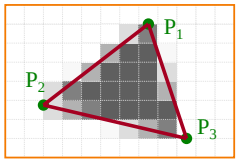
Hardware Scan Conversion

- Convert everything into triangles
  - Scan convert the triangles



Hardware Antialiasing

- Supersample pixels
  - Multiple samples per pixel
  - Average subpixel intensities (box filter)
  - Trades intensity resolution for spatial resolution



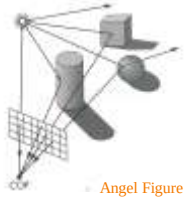
Overview

- Scan conversion
  - Figure out which pixels to fill
- Shading
  - Determine a color for each filled pixel
- Texture Mapping
  - Describe shading variation within polygon interiors
- Visible Surface Determination
  - Figure out which surface is front-most at every pixel

Shading

- How do we choose a color for each filled pixel?
  - Each illumination calculation for a ray from the eyepoint through the view plane provides a radiance sample
    - How do we choose where to place samples?
    - How do we filter samples to reconstruct image?

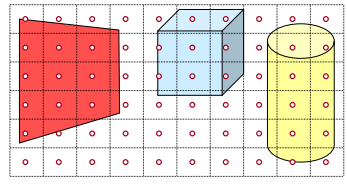
Emphasis on methods that can be implemented in hardware



Angel Figure 6.34

Ray Casting

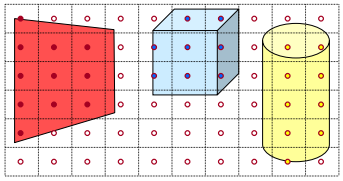
- Simplest shading approach is to perform independent lighting calculation for every pixel
  - When is this unnecessary?



$$I = I_E + K_A I_{AL} + \sum_i (K_D (N \bullet L_i) I_i + K_S (V \bullet R_i)^n I_i)$$

Polygon Shading

- Can take advantage of spatial coherence
  - Illumination calculations for pixels covered by same primitive are related to each other



$$I = I_E + K_A I_{AL} + \sum_i (K_D (N \bullet L_i) I_i + K_S (V \bullet R_i)^n I_i)$$

Polygon Shading Algorithms

- Flat Shading
- Gouraud Shading
- Phong Shading

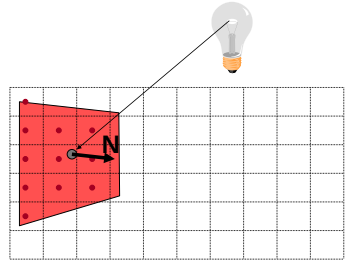
Flat Shading

- What if a faceted object is illuminated only by directional light sources and is either diffuse or viewed from infinitely far away

$$I = I_E + K_A I_{AL} + \sum_i (K_D (N \bullet L_i) I_i + K_S (V \bullet R_i)^n I_i)$$

Flat Shading

- One illumination calculation per polygon
  - Assign all pixels inside each polygon the same color



Flat Shading

- Objects look like they are composed of polygons
  - OK for polyhedral objects
  - Not so good for ones with smooth surfaces

Polygon Shading Algorithms

- Flat Shading
- **Gouraud Shading**
- Phong Shading

Gouraud Shading

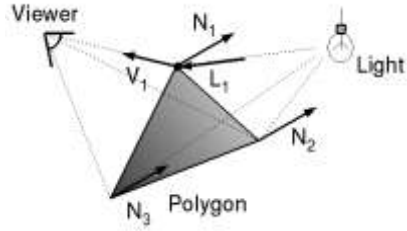
- What if smooth surface is represented by polygonal mesh with a normal at each vertex?

Watt Plate 7

$$I = I_E + K_A I_{AL} + \sum_i (K_D (N \bullet L_i) I_i + K_S (V \bullet R_i)^n I_i)$$

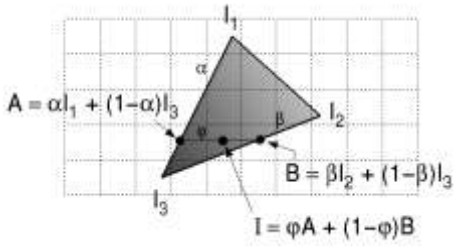
Gouraud Shading

- Method 1: One lighting calculation per vertex
  - Assign pixels inside polygon by interpolating colors computed at vertices



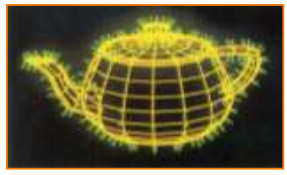
Gouraud Shading

- Bilinearly interpolate colors at vertices down and across scan lines



Gouraud Shading

- Smooth shading over adjacent polygons
  - Curved surfaces
  - Illumination highlights
  - Soft shadows



Mesh with shared normals at vertices

Watt Plate 7

Gouraud Shading

- Produces smoothly shaded polygonal mesh
  - Piecewise linear approximation
  - Need fine mesh to capture subtle lighting effects

Flat Shading

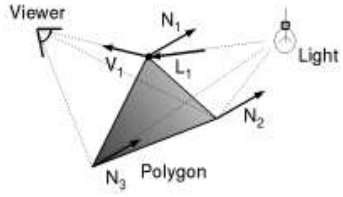
Gouraud Shading

Polygon Shading Algorithms

- Flat Shading
- Gouraud Shading
- **Phong Shading**

Phong Shading

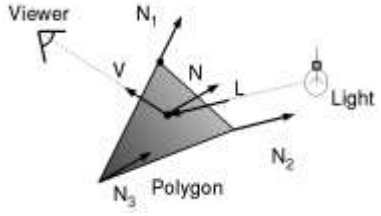
- What if polygonal mesh is too coarse to capture illumination effects in polygon interiors?



$$I = I_E + K_A I_{AL} + \sum_i (K_D (N \bullet L_i) I_i + K_S (V \bullet R_i)^n I_i)$$

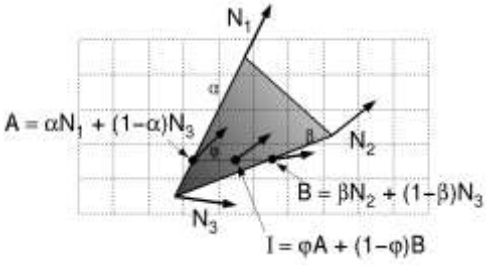
Phong Shading

- One lighting calculation per pixel
  - Approximate surface normals for points inside polygons by **bilinear interpolation of normals** from vertices

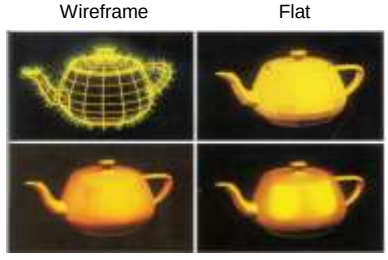


Phong Shading

- Bilinearly interpolate surface normals at vertices down and across scan lines



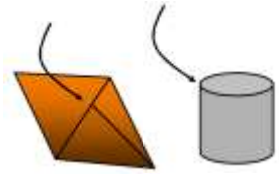
Polygon Shading Algorithms



Watt Plate 7

Shading Issues

- Problems with interpolated shading:
  - Polygonal silhouettes
  - Perspective distortion
  - Orientation dependence (due to bilinear interpolation)
  - Problems at T-vertices
  - Problems computing shared vertex normals



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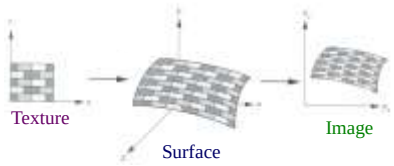
Textures

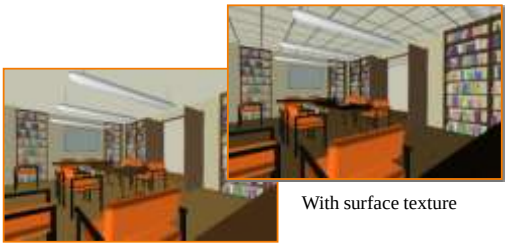
- Describe color variation in interior of 3D polygon
  - When scan converting a polygon, vary pixel colors according to values fetched from a texture



Angel Figure 9.3

Surface Textures

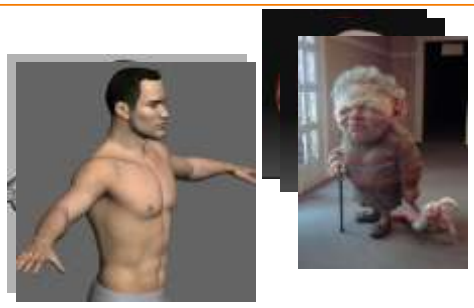
- Add visual detail to surfaces of 3D objects



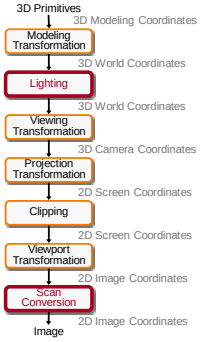
Polygonal model

With surface texture

Surface Textures



3D Rendering Pipeline (for direct illumination)



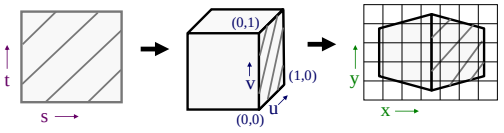
Texture mapping

Overview

- Texture mapping methods
  - Mapping
  - Filtering
  - Parameterization
- Texture mapping applications
  - Modulation textures
  - Illumination mapping
  - Bump mapping
  - Environment mapping
  - Image-based rendering
  - Non-photorealistic rendering

Texture Mapping

- Steps:
  - Define texture
  - Specify mapping from texture to surface
  - Lookup texture values during scan conversion



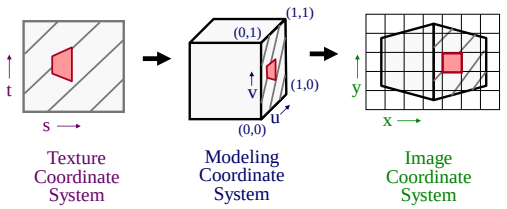
Texture Coordinate System

Modeling Coordinate System

Image Coordinate System

Texture Mapping

- When scan convert, map from …
  - image coordinate system (x,y) to
  - modeling coordinate system (u,v) to
  - texture image (t,s)



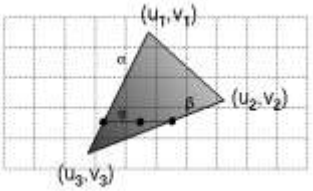
Texture Mapping

- Texture mapping is a 2D projective transformation
  - texture coordinate system: (t,s) to
  - image coordinate system (x,y)

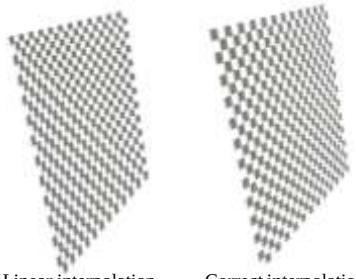
Chris Buehler & Leonard McMillan, MIT

Texture Mapping

- Scan conversion
  - Interpolate texture coordinates down/across scan lines
  - Distortion due to bilinear interpolation approximation
    - Cut polygons into smaller ones, or
    - Perspective divide at each pixel



Texture Mapping



Linear interpolation of texture coordinates

Correct interpolation with perspective divide

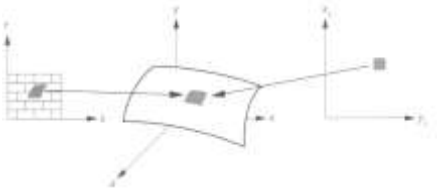
Hill Figure 8.42

Overview

- Texture mapping methods
  - Mapping
  - Filtering
  - Parameterization
- Texture mapping applications
  - Modulation textures
  - Illumination mapping
  - Bump mapping
  - Environment mapping
  - Image-based rendering
  - Non-photorealistic rendering

Texture Filtering

- Must sample texture to determine color at each pixel in image



Angel Figure 9.4

Texture Filtering

- Aliasing is a problem

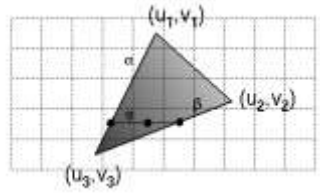
Point sampling

Area filtering

Angel Figure 9.5

Texture Mapping

- Scan conversion
  - Interpolate texture coordinates down/across scan lines
  - Distortion due to bilinear interpolation approximation
    - Cut polygons into smaller ones, or
    - Perspective divide at each pixel



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Linear interpolation
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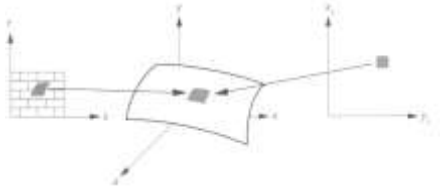


Angel Figure 9.4

Texture Filtering

- Aliasing is a problem

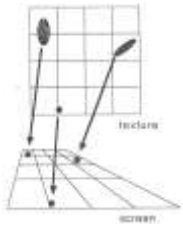
Point sampling

Area filtering

Angel Figure 9.5

Texture Filtering

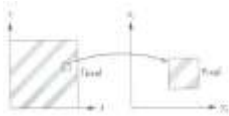
- Ideally, use elliptically shaped convolution filters



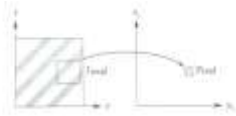
In practice, use rectangles

Texture Filtering

- Size of filter depends on projective warp
  - Can prefiltering images
    - Mip maps
    - Summed area tables



Magnification

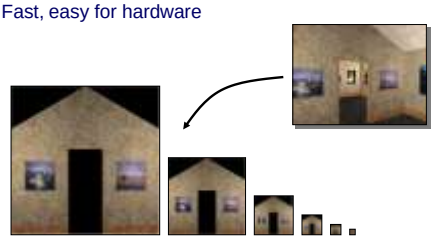


Minification

Angel Figure 9.14

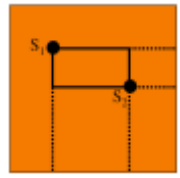
Mip Maps

- Keep textures prefiltered at multiple resolutions
  - For each pixel, linearly interpolate between two closest levels (e.g., trilinear filtering)
  - Fast, easy for hardware



Summed-area tables

- At each texel keep sum of all values down&right
  - To compute sum of all values within a rectangle simply subtract two entries
  - Better ability to capture very oblique projections
  - But, cannot store values in a single byte



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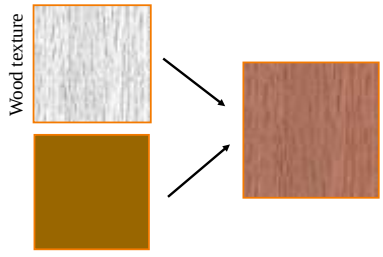
Modulation textures

- Map texture values to scale factor



$$I = T(s,t)(I_E + K_A I_A + \sum_L (K_D(N \bullet L) + K_S(V \bullet R)^n) S_L I_L + K_T I_T + K_S I_S)$$

Illumination Mapping

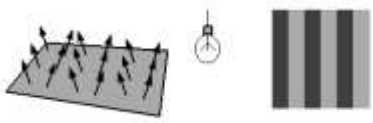
- Map texture values to surface material parameter
  - K_A
  - K_D
  - K_S
  - K_T
  - n

$K_T = T(s,t)$

$$I = I_E + K_A I_A + \sum_L (K_D(N \bullet L) + K_S(V \bullet R)^n) S_L I_L + K_T I_T + K_S I_S$$

Bump Mapping

- Map texture values to perturbations of surface normals

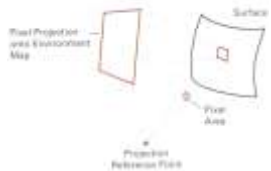


Bump Mapping

H&B Figure 14.100

Environment Mapping

- Map texture values to perturbations of surface normals



H&B Figure 14.93

Image-Based Rendering

- Map photographic textures to provide details for coarsely detailed polygonal model

Solid Textures

- Texture values indexed by 3D location
  - Expensive storage, or
  - Compute on the fly, E.g Perlin noise

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