Scan Conversion

COS 426, Spring 2019
Princeton University

3D Rendering Pipeline (for direct illumination)

3D Primitives

↓

Modeling Transformation

↓

Lighting

↓

Viewing Transformation

↓

Projection Transformation

↓

Clipping

↓

Viewport Transformation

↓

Scan Conversion

↓

Image

Rasterization

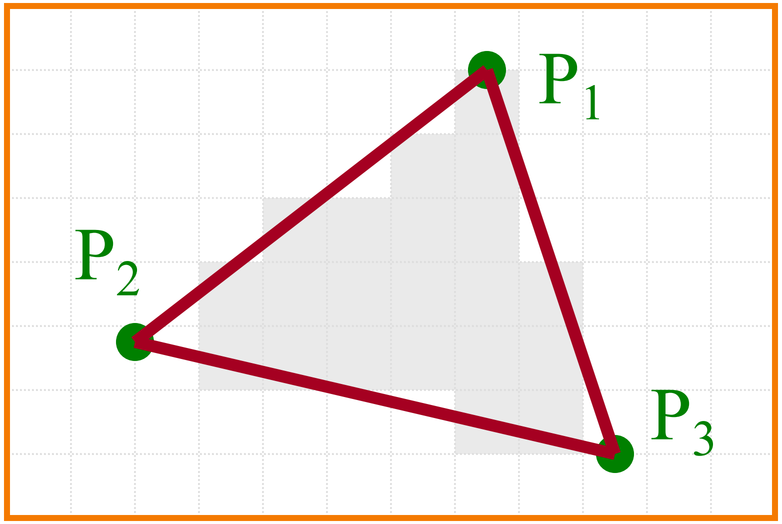
- Scan conversion
  - Determine which pixels to fill
- Shading
  - Determine a color for each filled pixel
- Texture mapping
  - Describe shading variation within polygon interiors
- Visible surface determination
  - Figure out which surface is front-most at every pixel

Rasterization

- Scan conversion (last time)
  - Determine 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

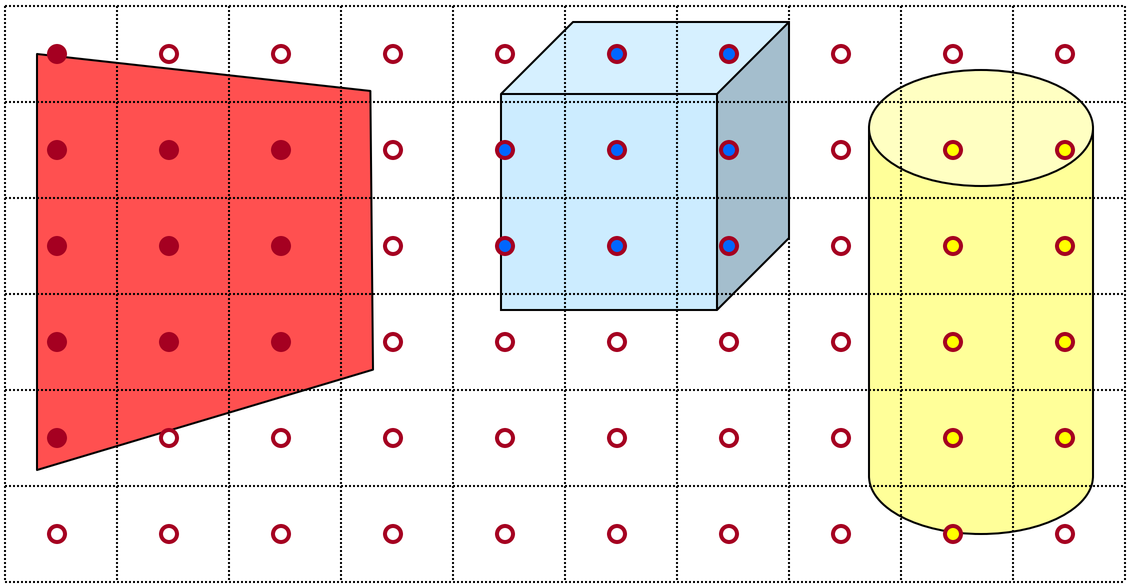
- How do we choose a color for each filled pixel?



Emphasis on methods that can be implemented in hardware

Ray Casting

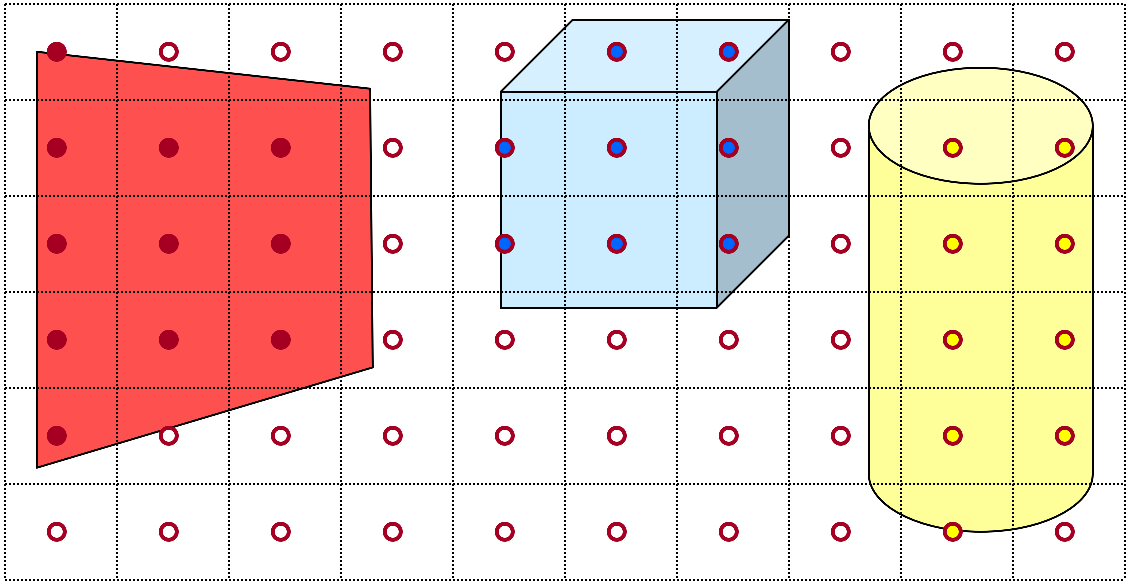
- Simplest shading approach is to perform independent lighting calculation for every pixel



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

Polygon Shading

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



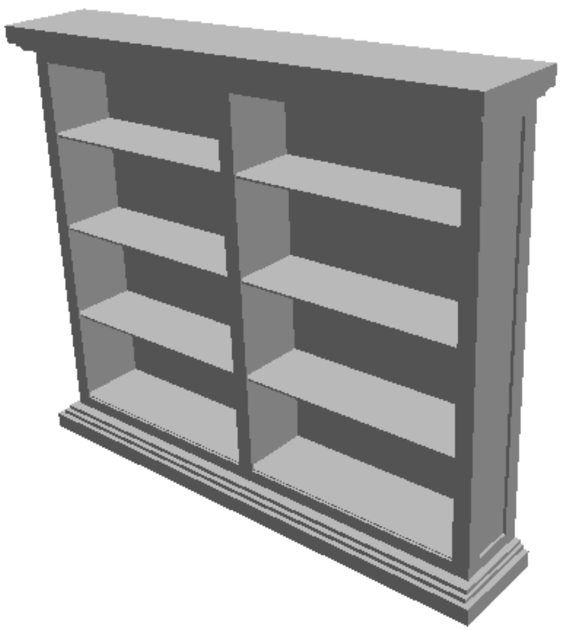
$$I = I_E + K_A I_{AL} + \sum_i \left(K_D (N \cdot L_i) I_i + K_S (V \cdot R_i)^n I_i \right)$$

Polygon Shading Algorithms

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

Flat Shading

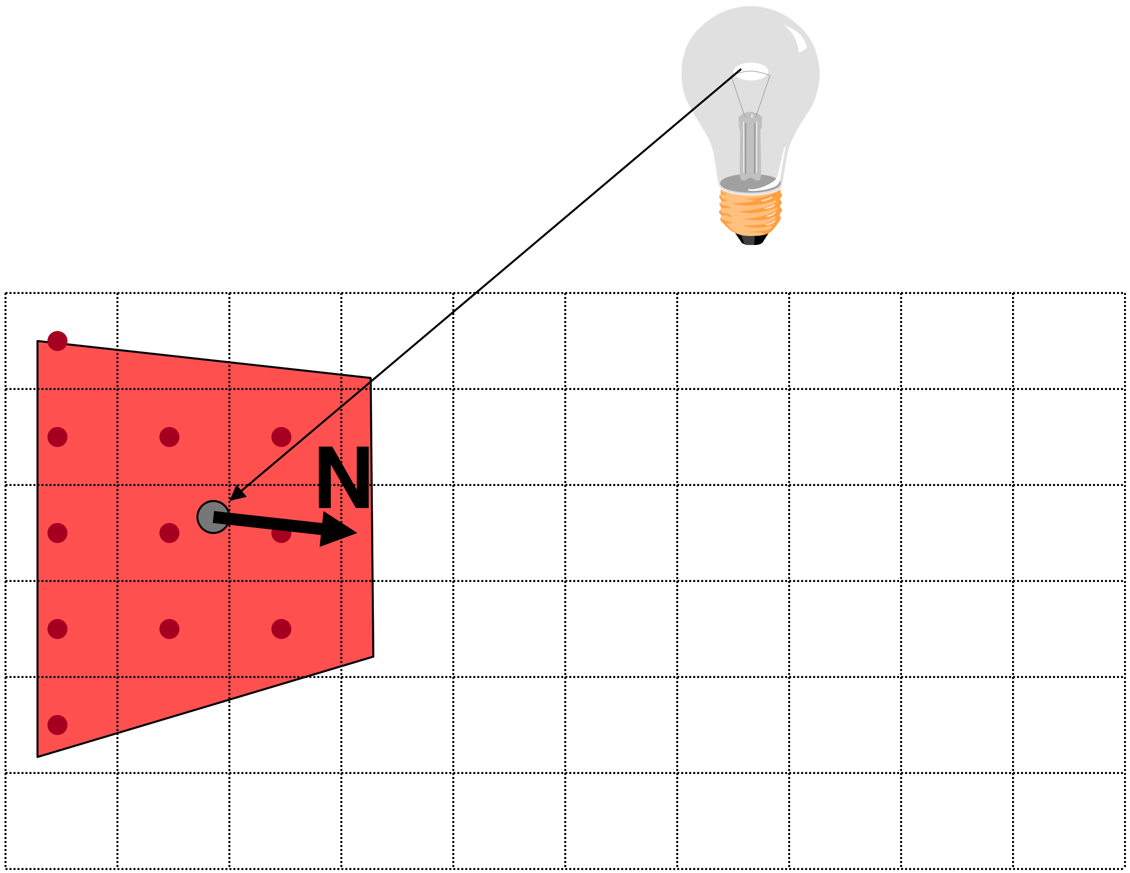
- What if a faceted object is illuminated only by directional light sources and is either diffuse or viewed from infinitely far away



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

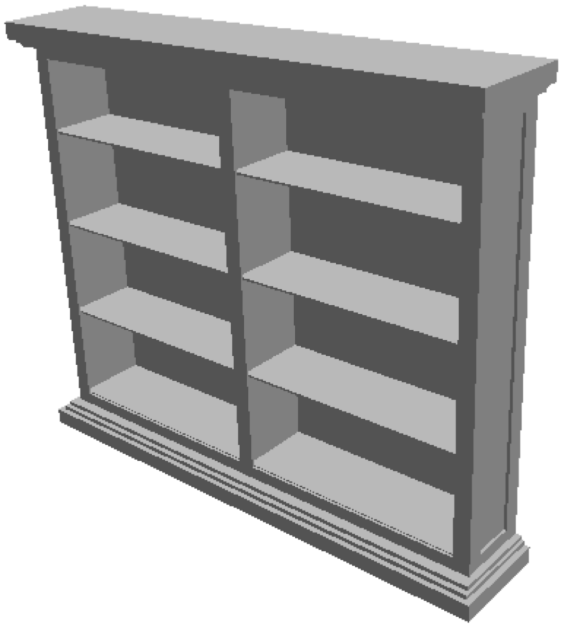
Flat Shading

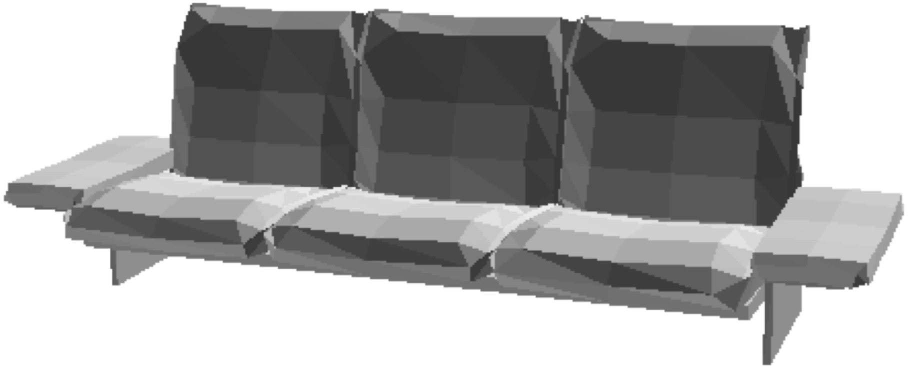
- One illumination calculation per polygon
  - Assign all pixels inside each polygon the same color



Flat Shading

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



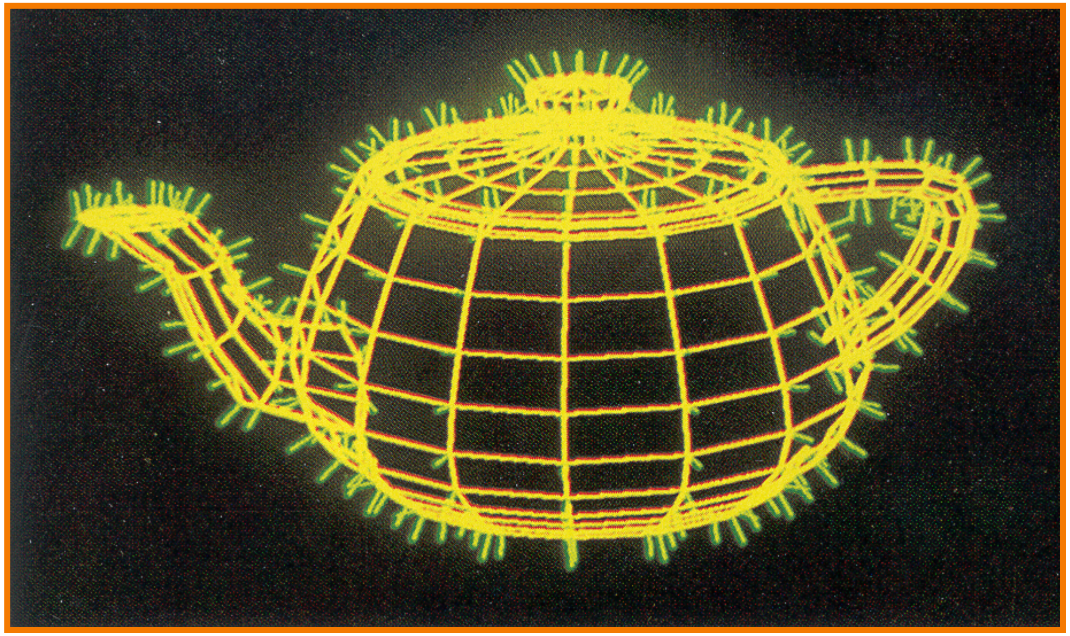


Polygon Shading Algorithms

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

Gouraud Shading

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

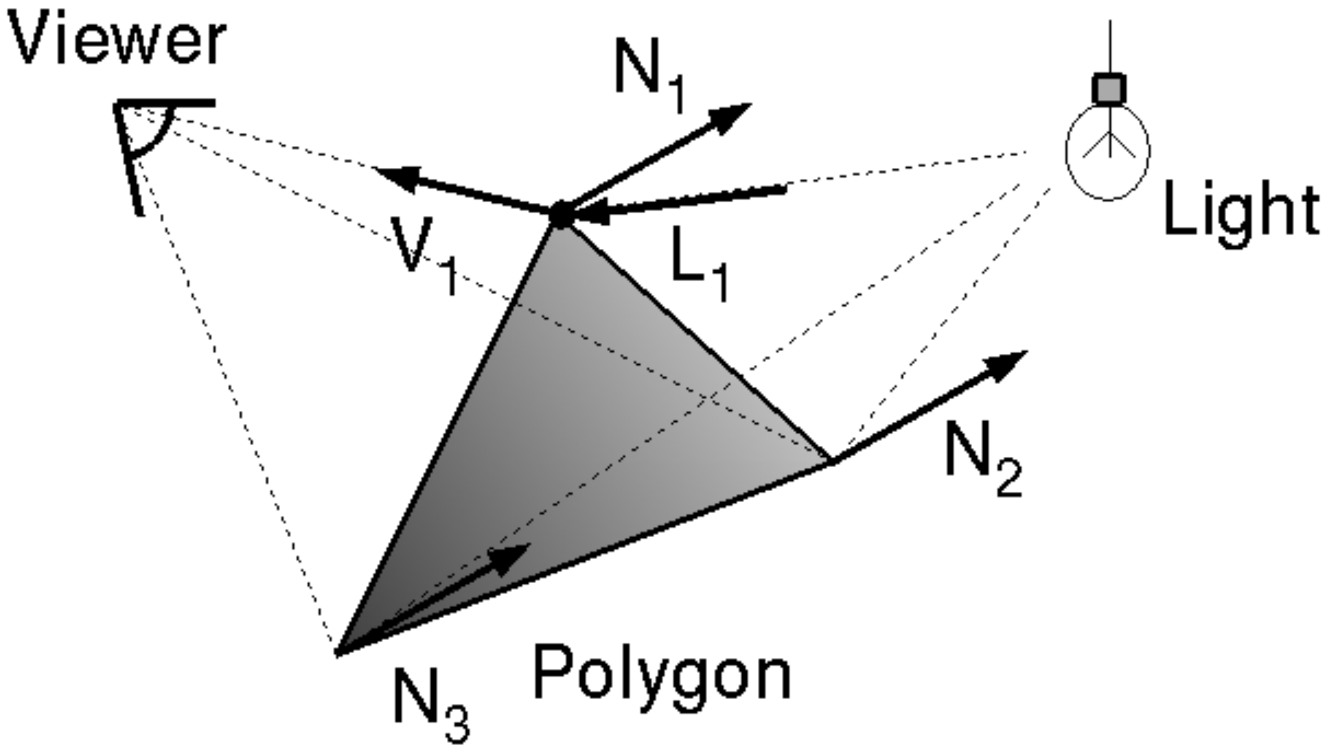


Watt Plate 7

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

Gouraud Shading

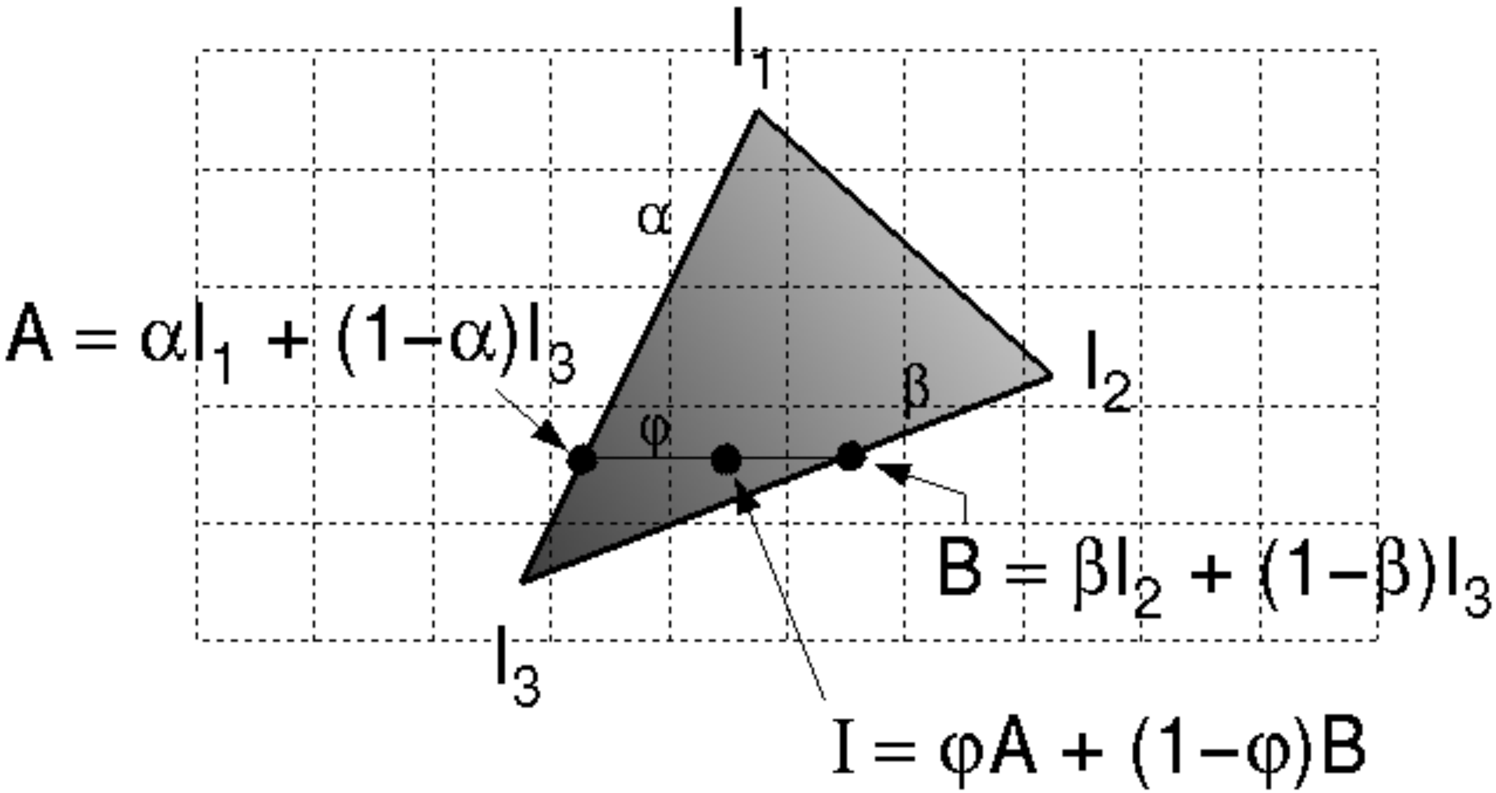
- Method 1: One lighting calculation per vertex
  - Assign pixels inside polygon by interpolating colors computed at vertices



Gouraud Shading

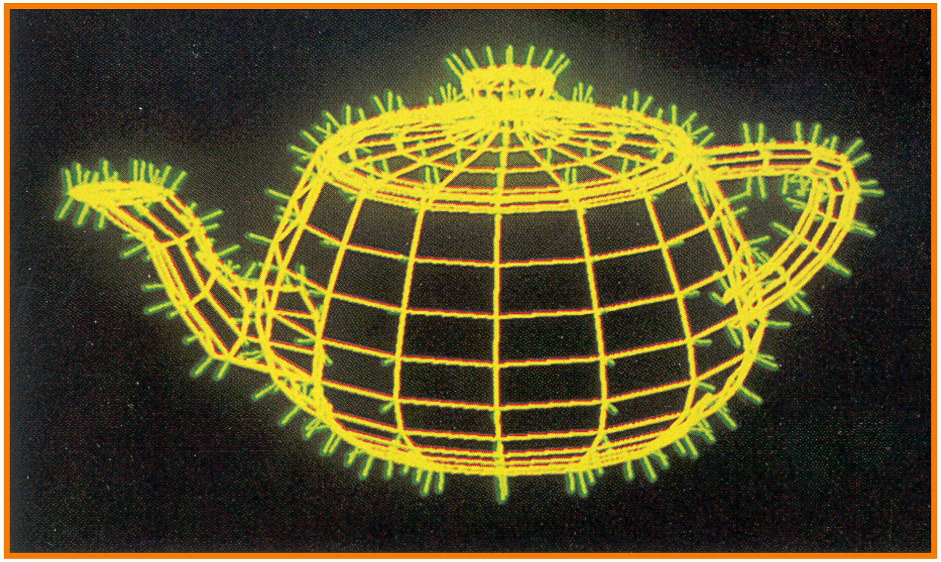
Bilinear interpolation of colors at vertices

- down and across scan lines = barycentric coords



Gouraud Shading

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

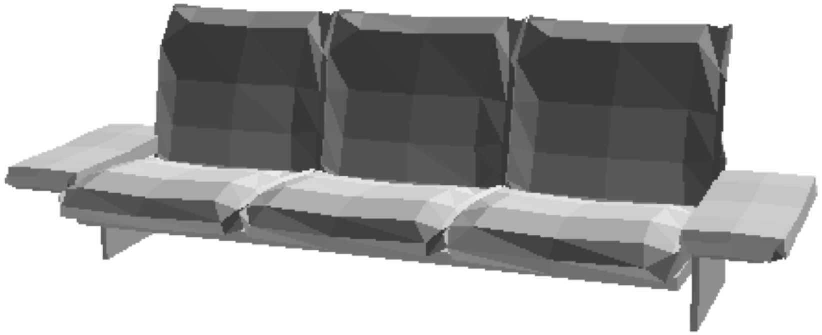


Mesh with shared normals at vertices

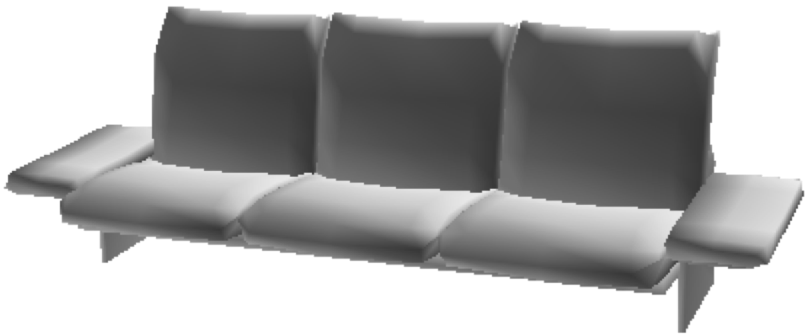
Watt Plate 7

Gouraud Shading

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



Flat Shading



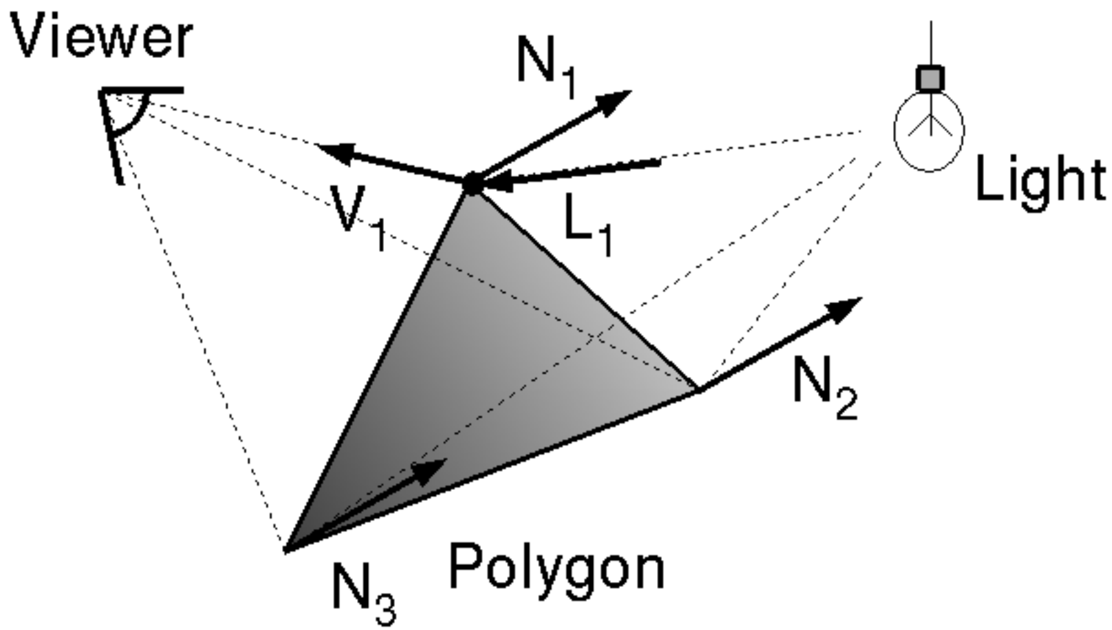
Gouraud Shading

Polygon Shading Algorithms

- Flat Shading
- Gouraud Shading
- **Phong Shading** (≠ Phong reflectance model)

Phong Shading

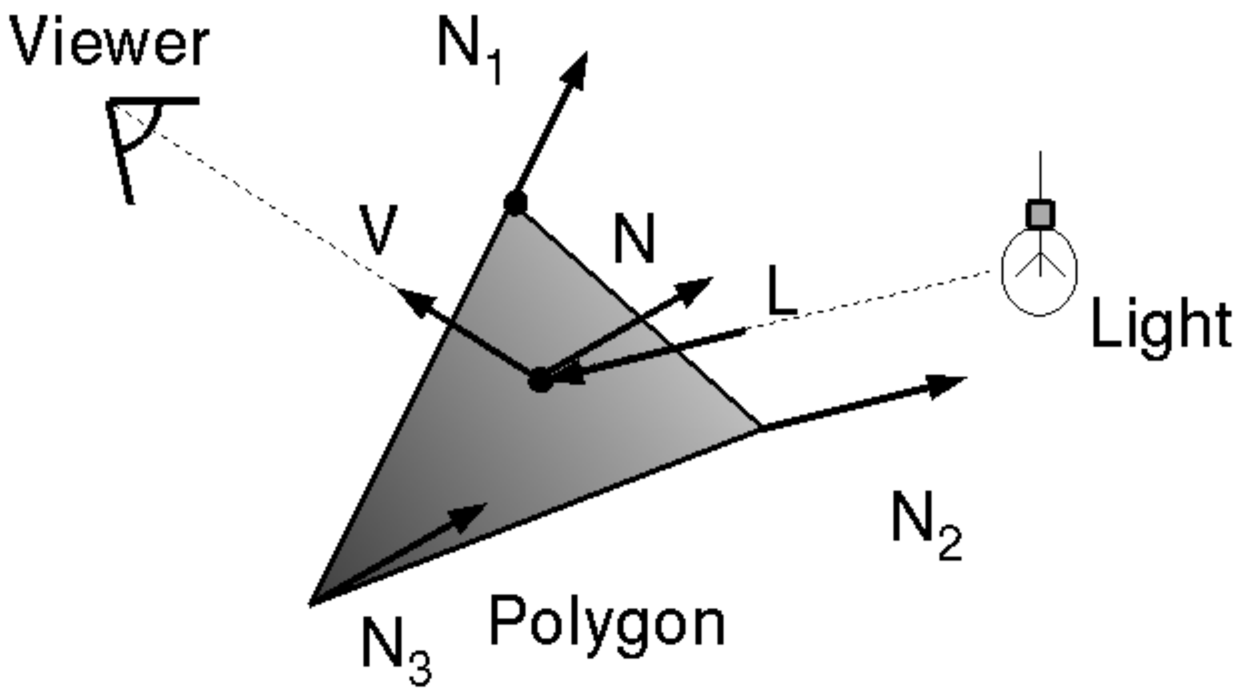
- What if polygonal mesh is too coarse to capture illumination effects in polygon interiors?



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

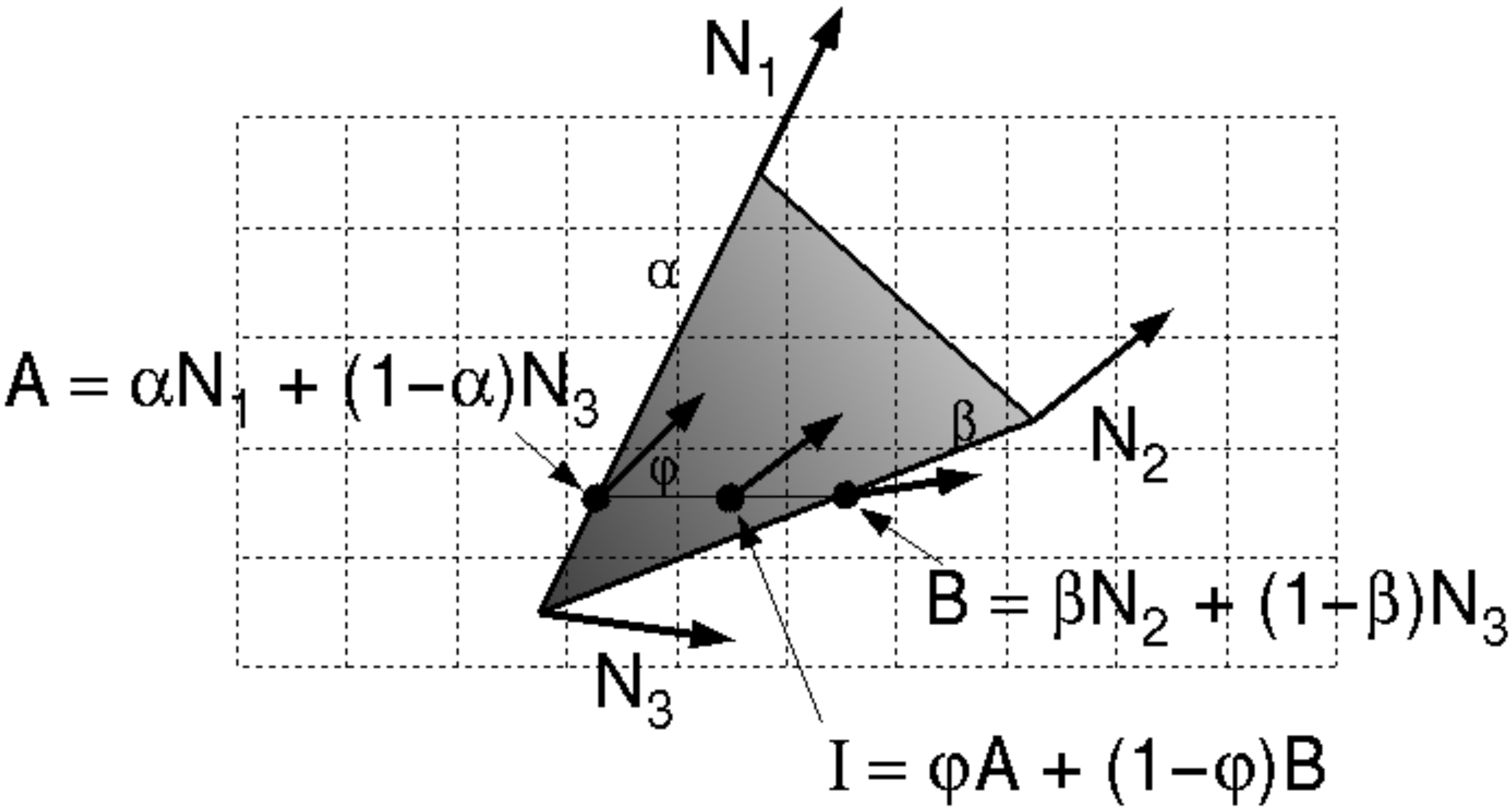
Phong Shading

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



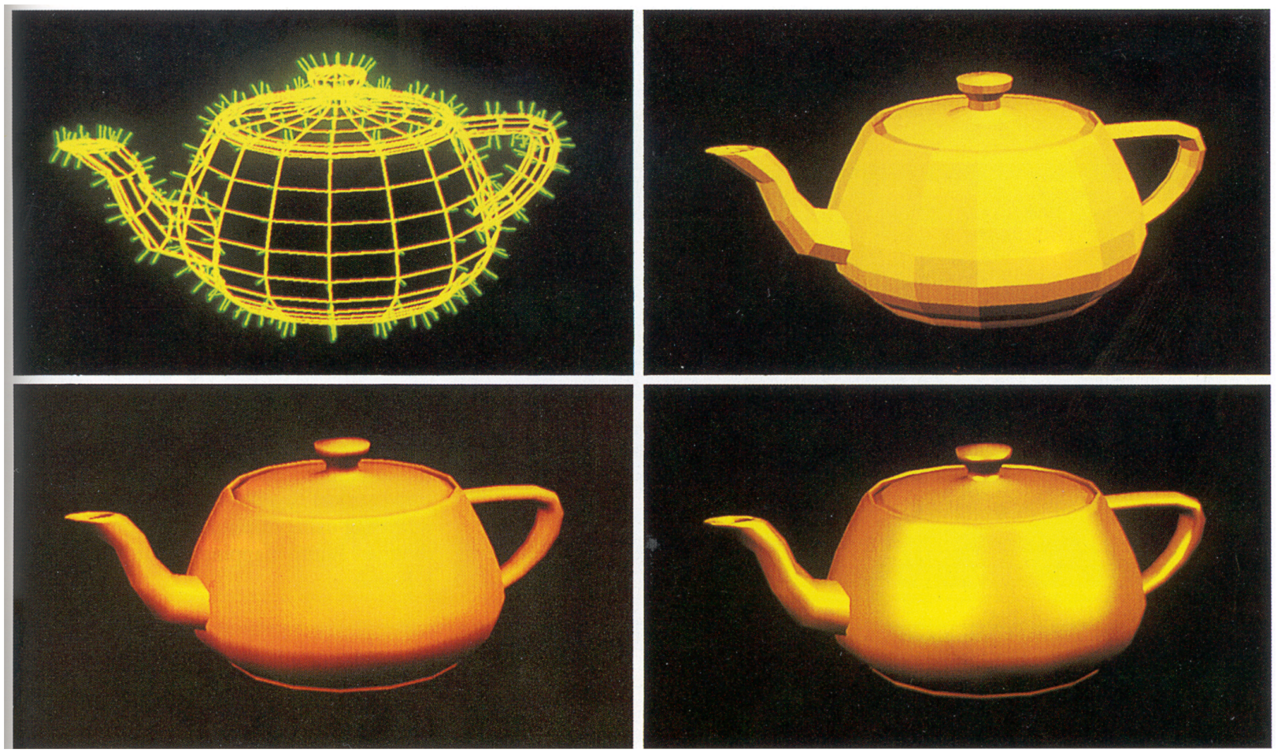
Phong Shading

Bilinear interpolation of surface normals at vertices



Polygon Shading Algorithms

Wireframe | Flat



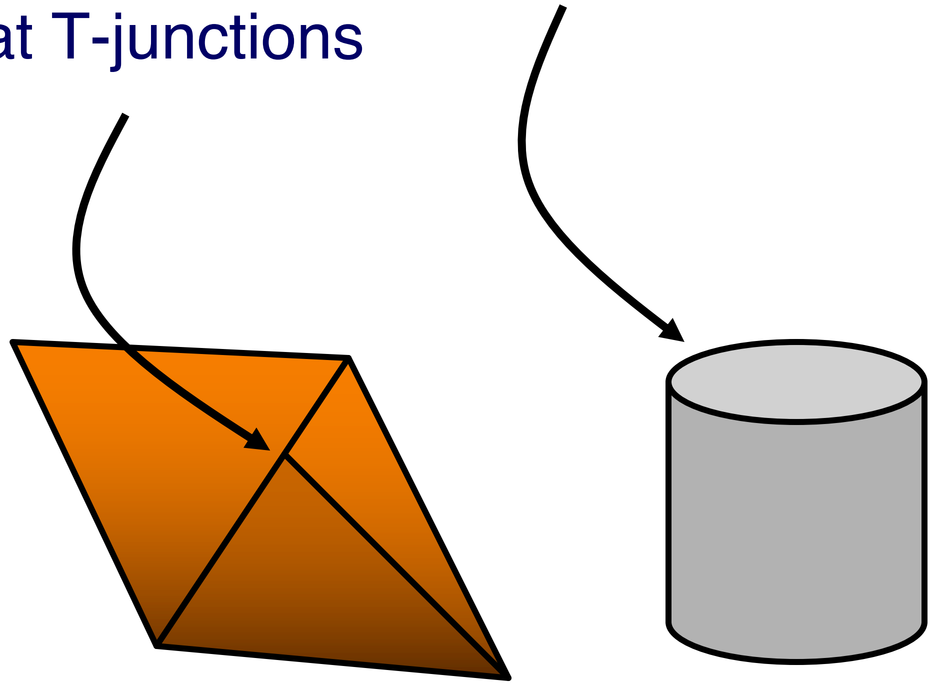
Gouraud | Phong

Demo: https://threejs.org/docs/scenes/material-browser.html#MeshPhongMaterial

Watt Plate 7

Shading Issues

- Problems with interpolated shading:
  - Polygonal silhouettes still obvious
  - Perspective distortion (due to screen-space interpolation)
  - Problems computing shared vertex normals
  - Problems at T-junctions



Rasterization

- Scan conversion
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- Texture mapping
  - Describe shading variation within polygon interiors
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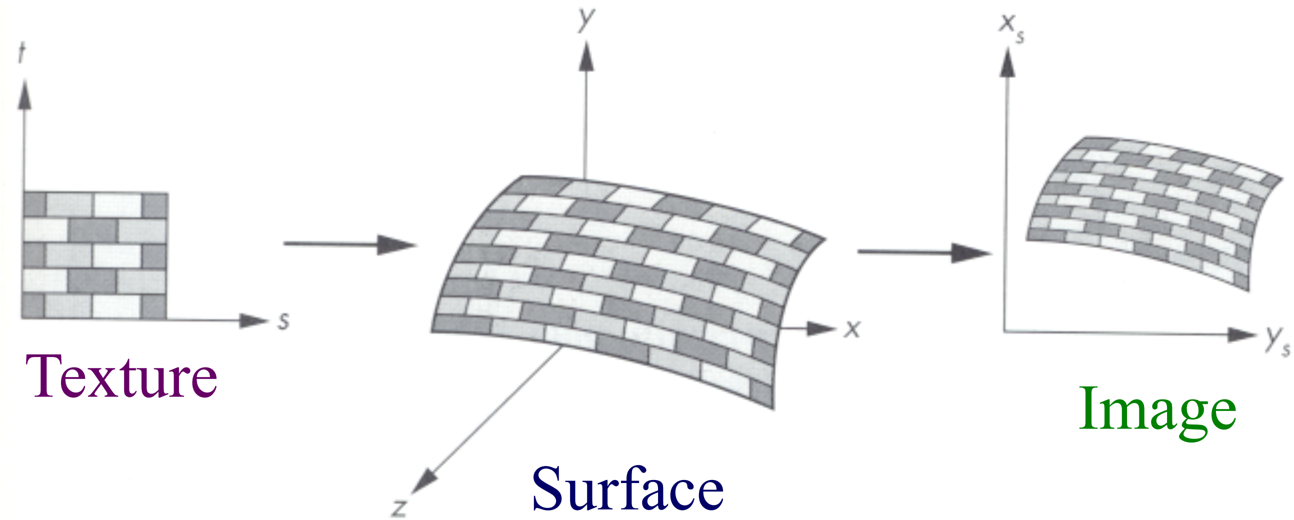
Textures

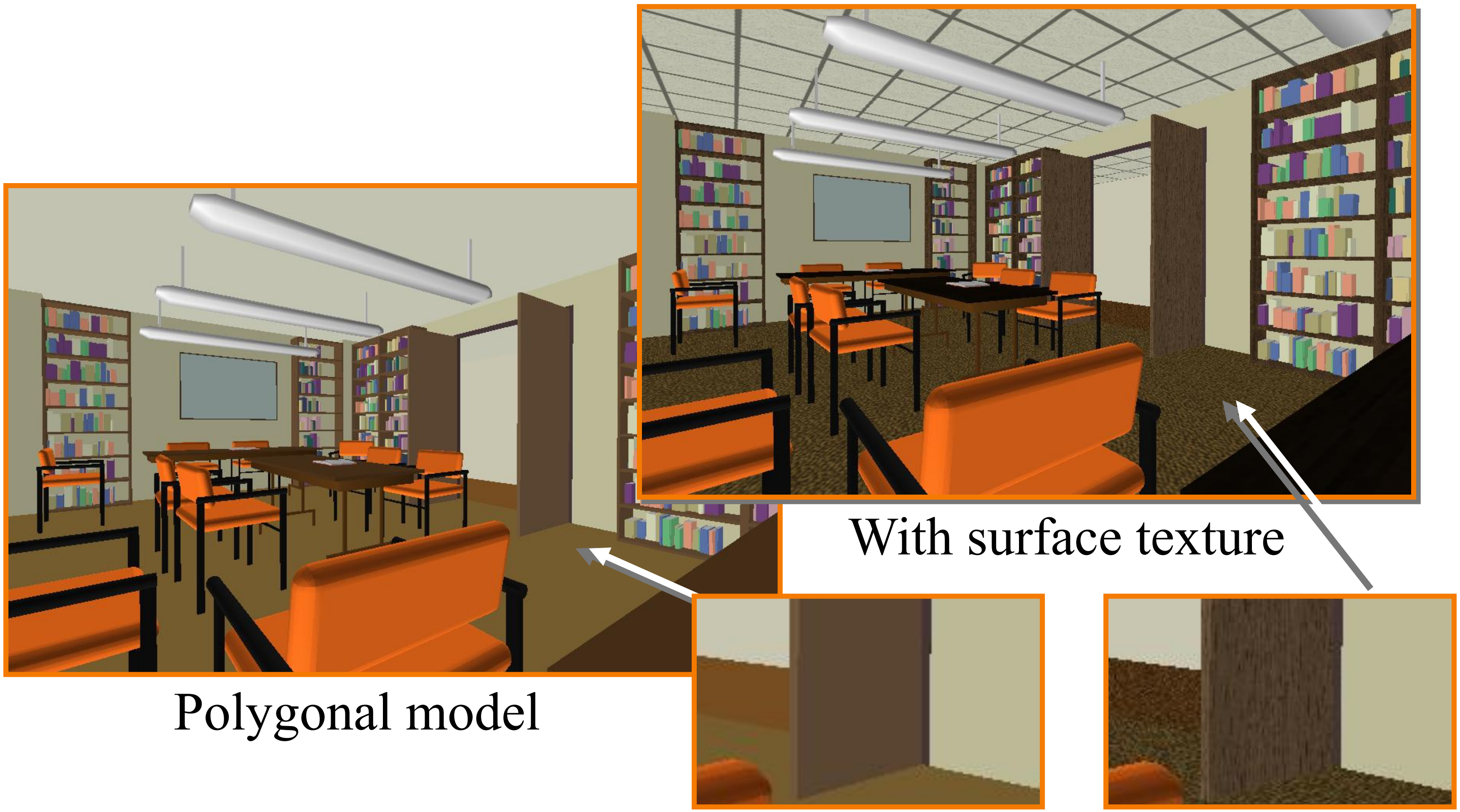
- Describe color variation in interior of 3D polygon
  - When scan converting a polygon, vary pixel colors according to values fetched from a texture image



Angel Figure 9.3

Surface Textures

- Add visual detail to surfaces of 3D objects



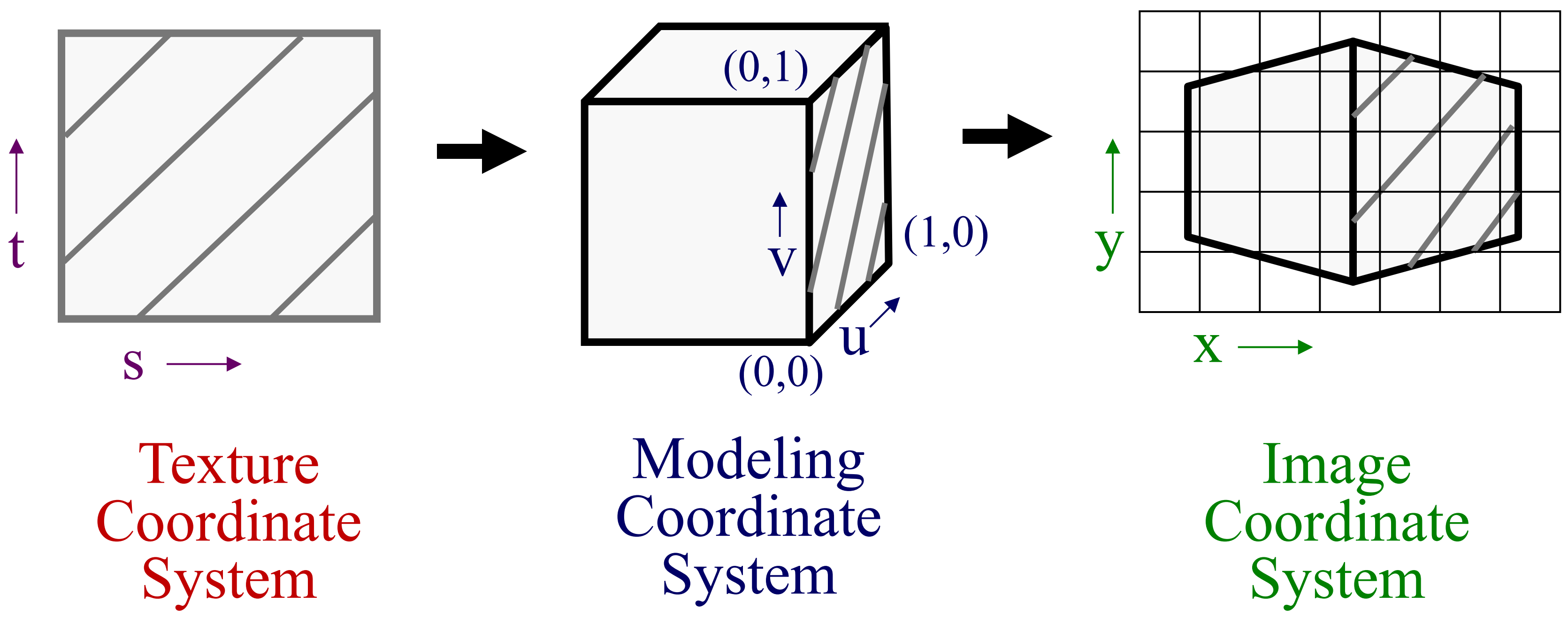
Textures

- Add visual detail to surfaces of 3D objects

[Daren Horley]

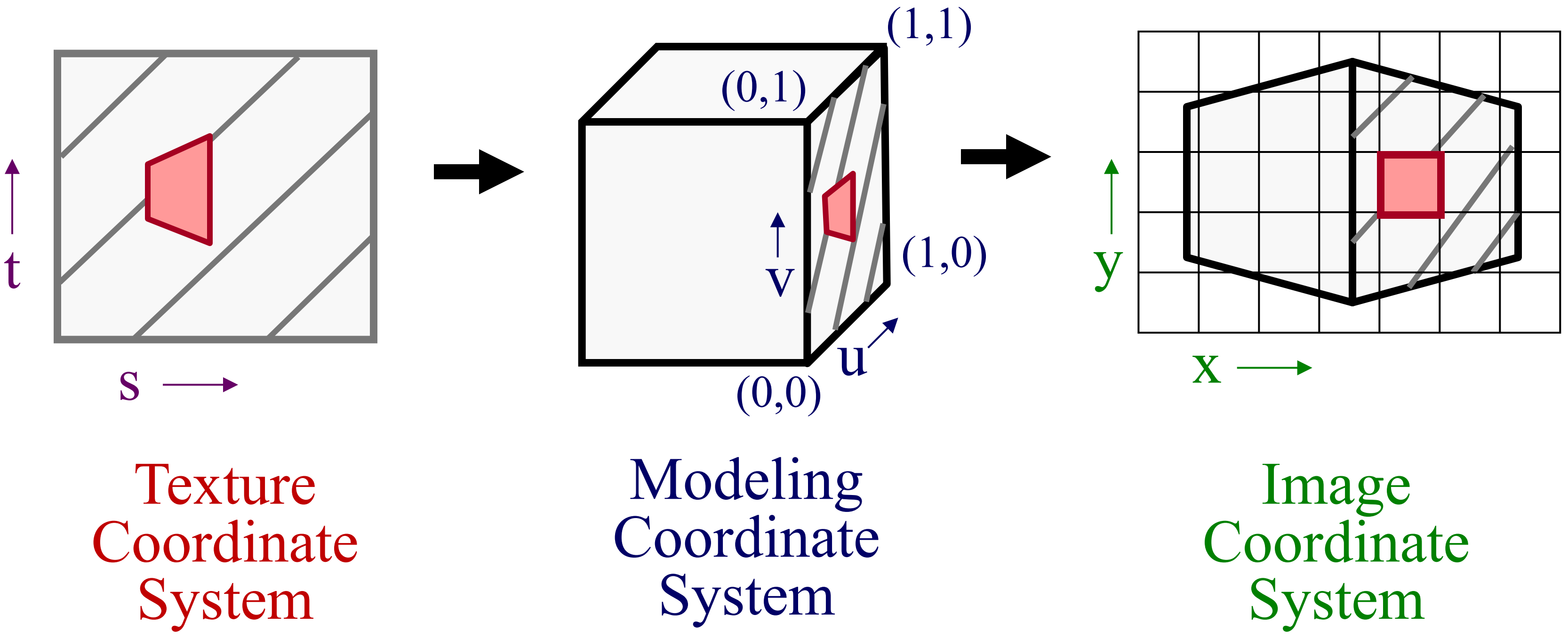
Texture Mapping

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



Texture Mapping

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



Texture Overview

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

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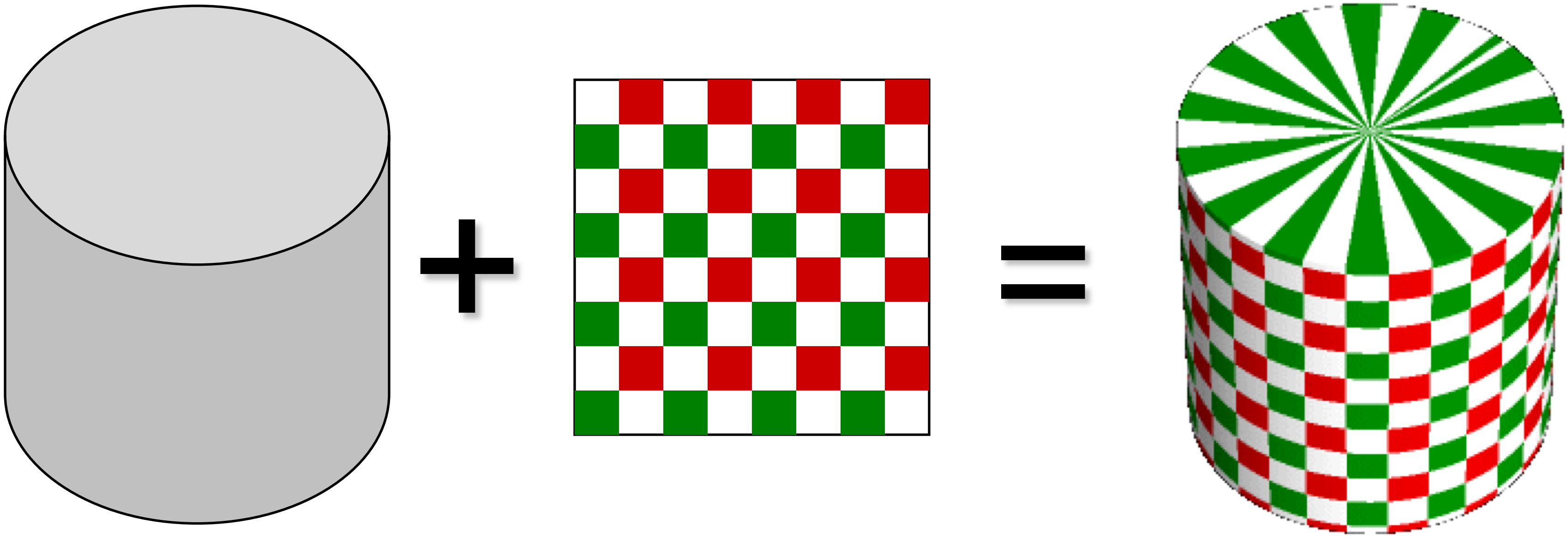
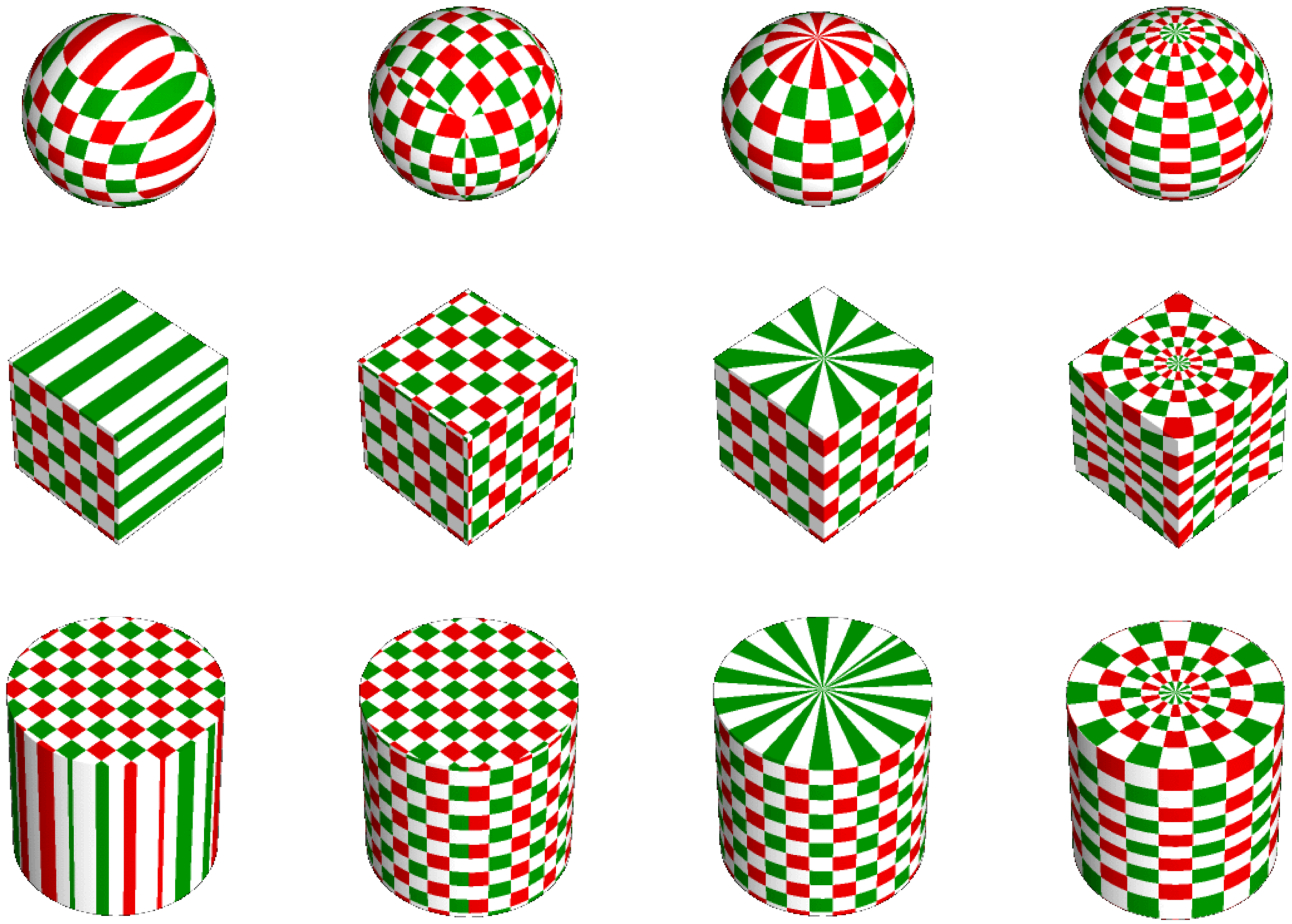
Texture Parameterization



geometry image texture map

- Q: How do we decide *where* on the geometry each color from the image should go?

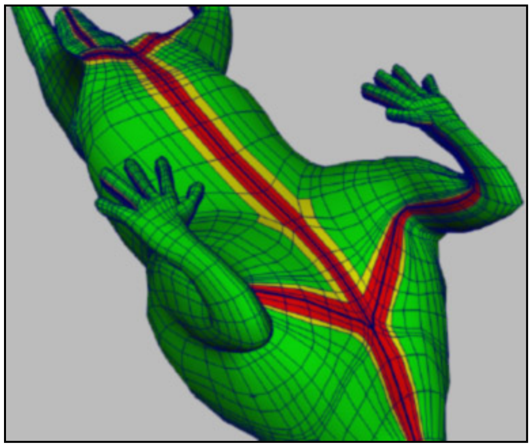
Texture Parameterization

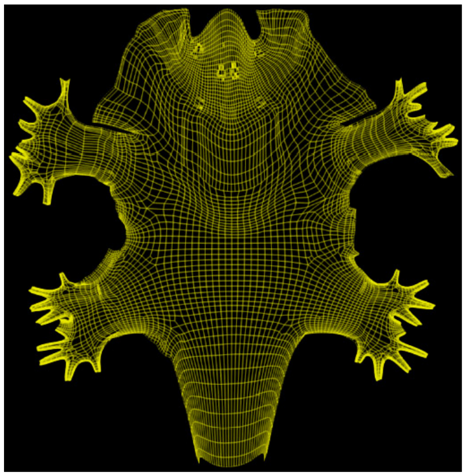


[Paul Bourke]

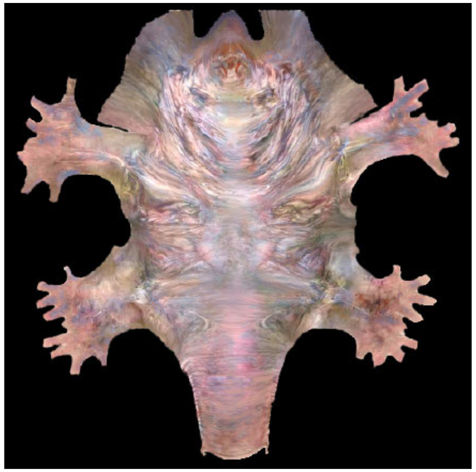
Texture Parameterization

Option1: unfold the surface





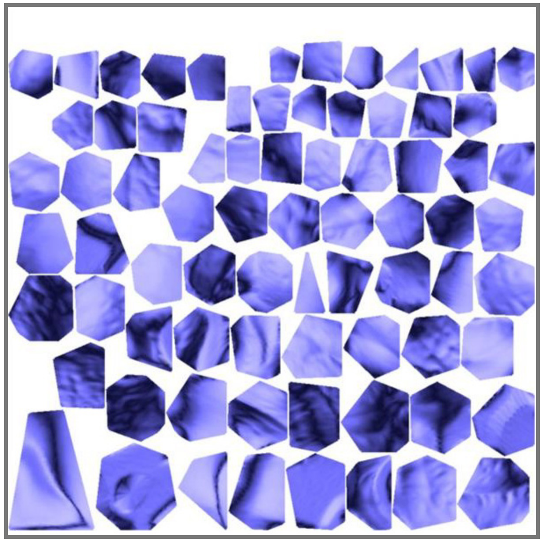
[Piponi2000]



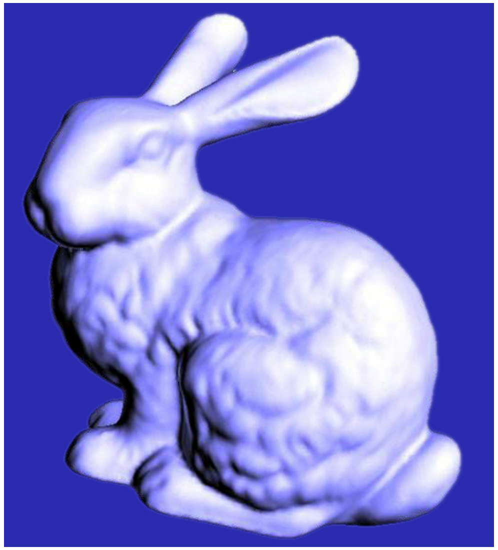
Texture Parameterization

Option2: make an atlas

charts



atlas



surface

[Sander2001]

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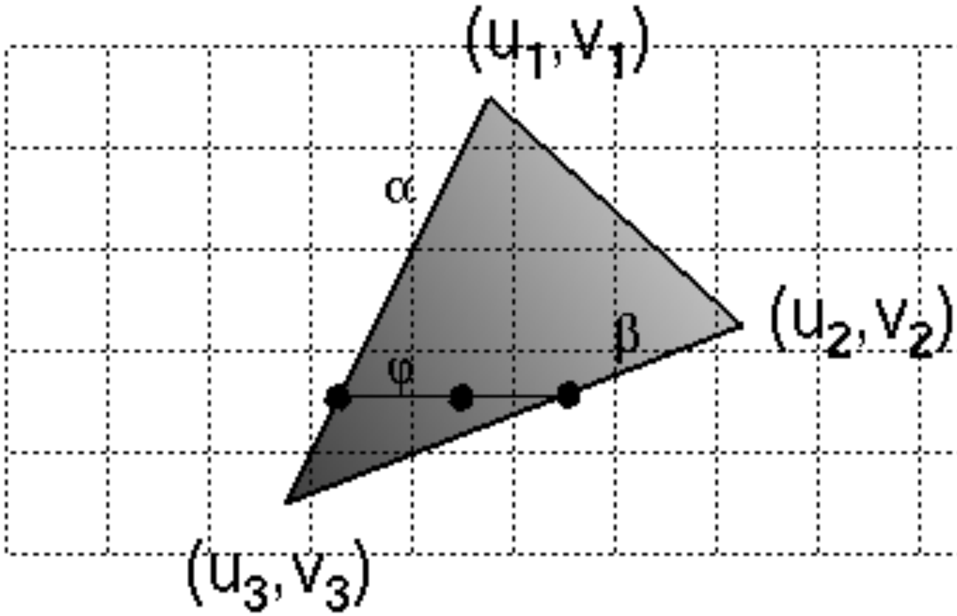
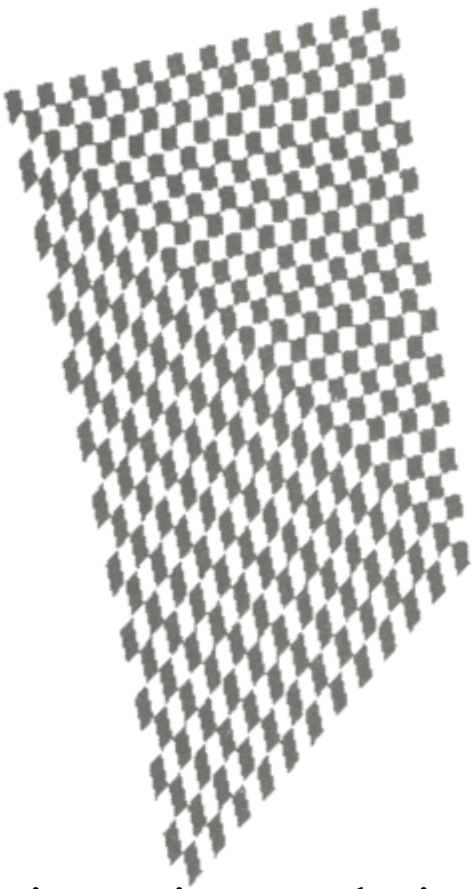
Texture Mapping

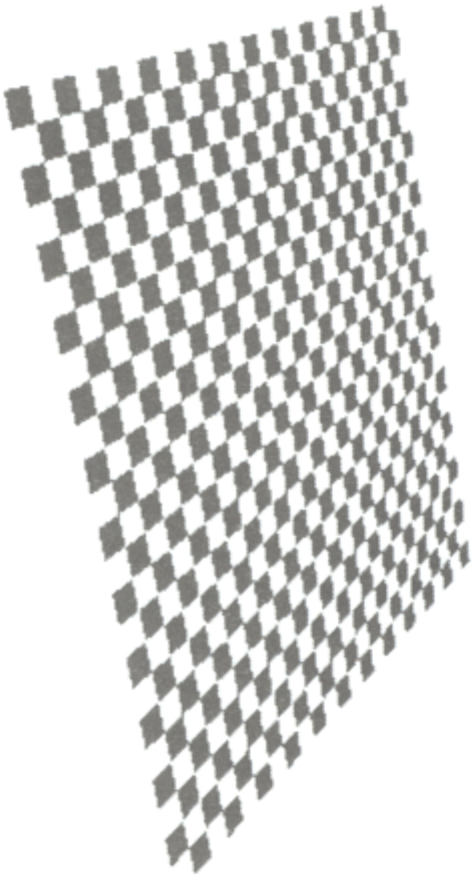
- Scan conversion
  - Interpolate texture coordinates down/across scan lines
  - Distortion due to bilinear interpolation approximation
    - » Cut polygons into smaller ones, or
    - » Perspective divide at each pixel



Texture Mapping



Linear interpolation
of texture coordinates



Correct interpolation
with perspective divide

Hill Figure 8.42

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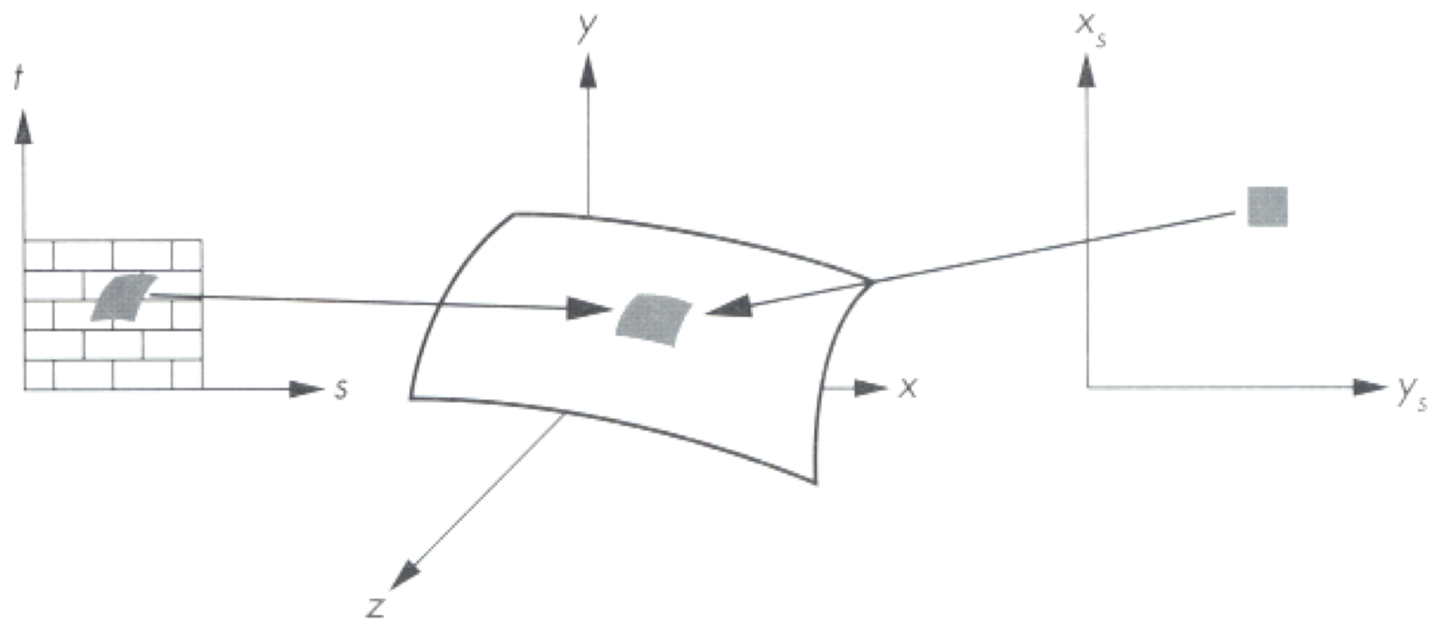
Texture Filtering

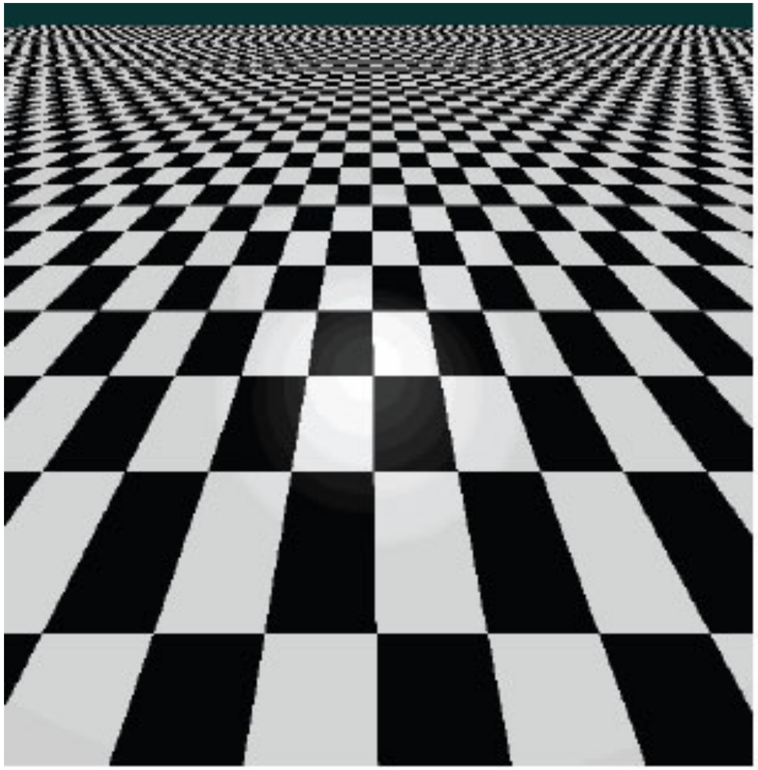
- Must sample texture to determine color at each pixel in image



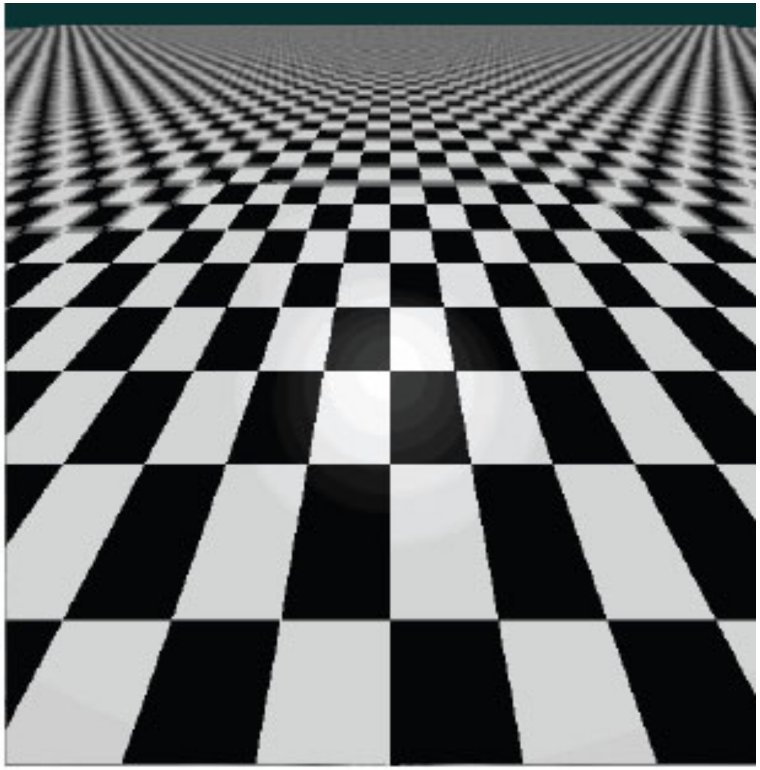
Angel Figure 9.4

Texture Filtering

- Aliasing is a problem



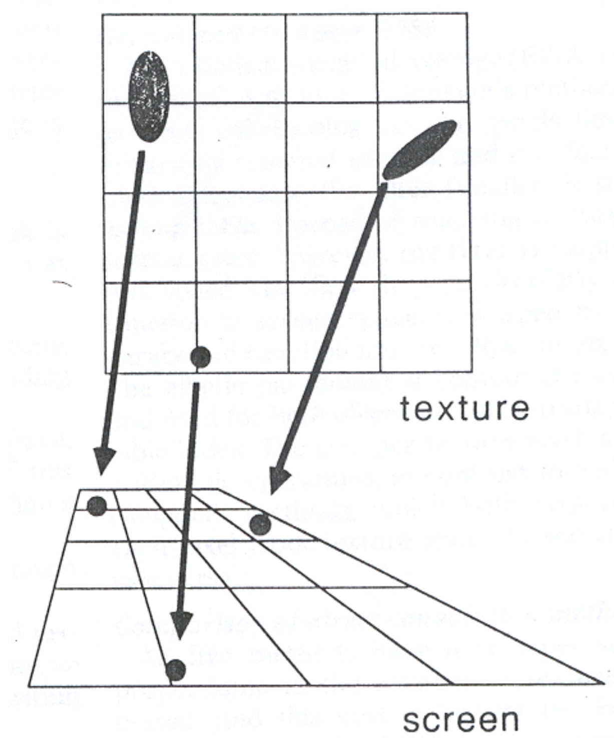
Point sampling



Area filtering

Texture Filtering

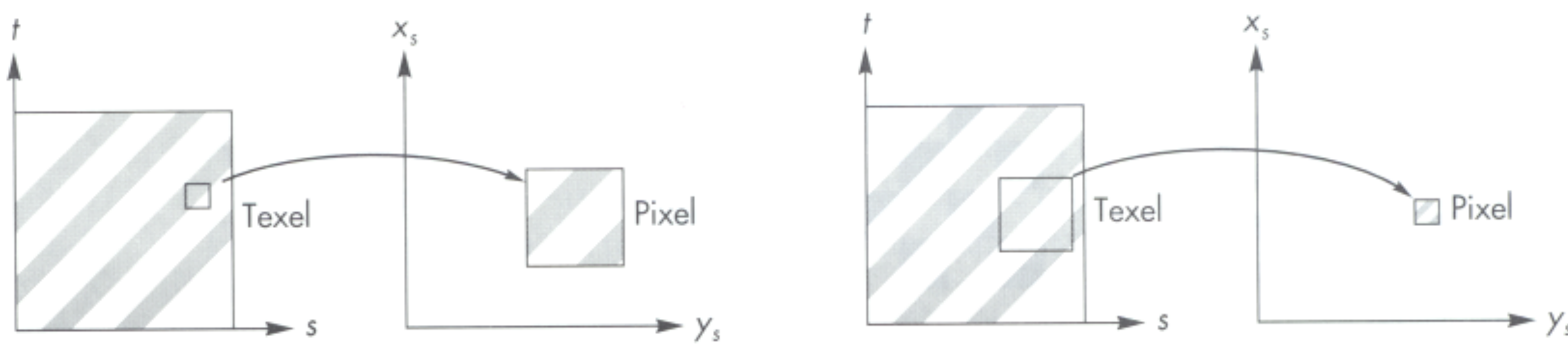
- Ideally, use elliptically shaped convolution filters



In practice, use rectangles or squares

Texture Filtering

- Size of filter depends on projective warp
  - Compute prefiltered images to avoid run-time cost
    - » Mipmaps
    - » Summed area tables

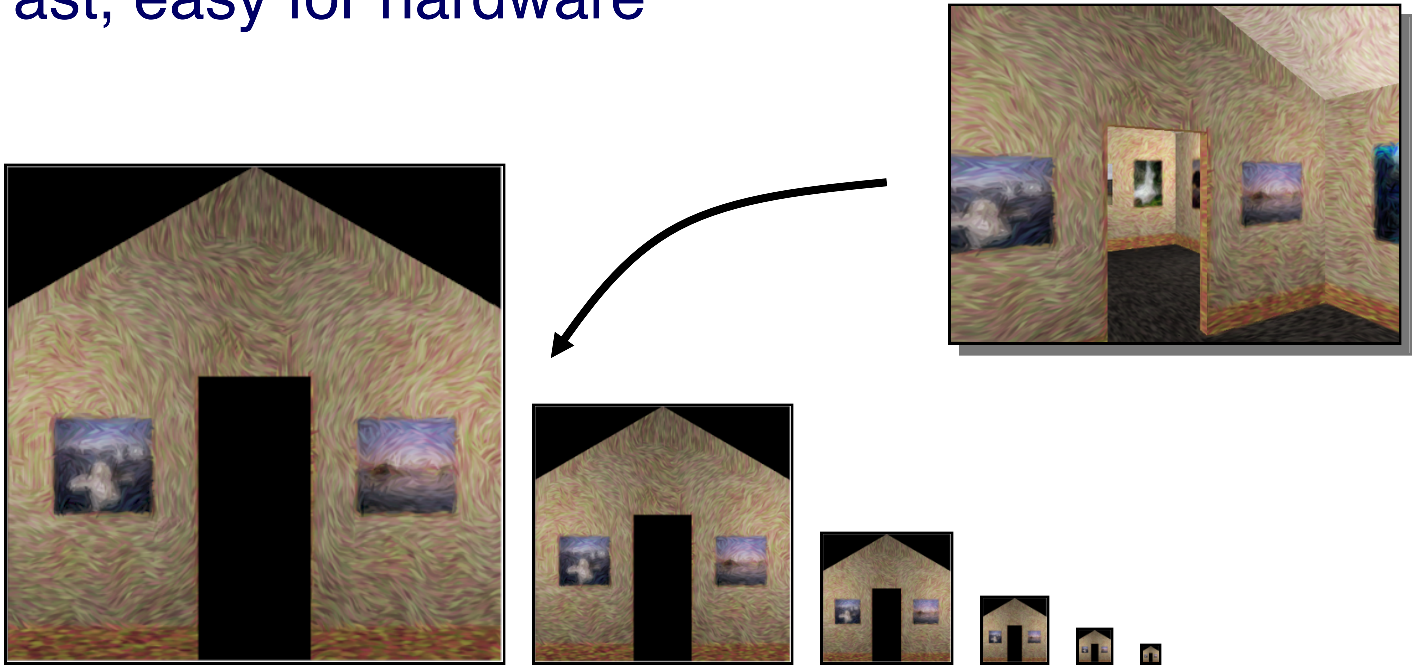


Magnification Minification

Angel Figure 9.14

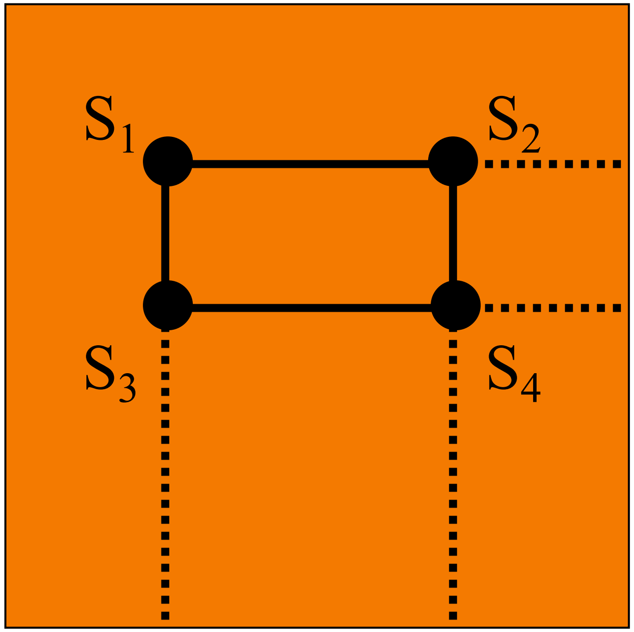
Mipmaps

- Keep textures prefiltered at multiple resolutions
  - Usually powers of 2
  - For each pixel, linearly interpolate between two closest levels (i.e., 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 combine four entries: $S_1 - S_2 - S_3 + S_4$
  - Better ability to capture oblique projections, but still not perfect



  - (Mipmaps are more common.)

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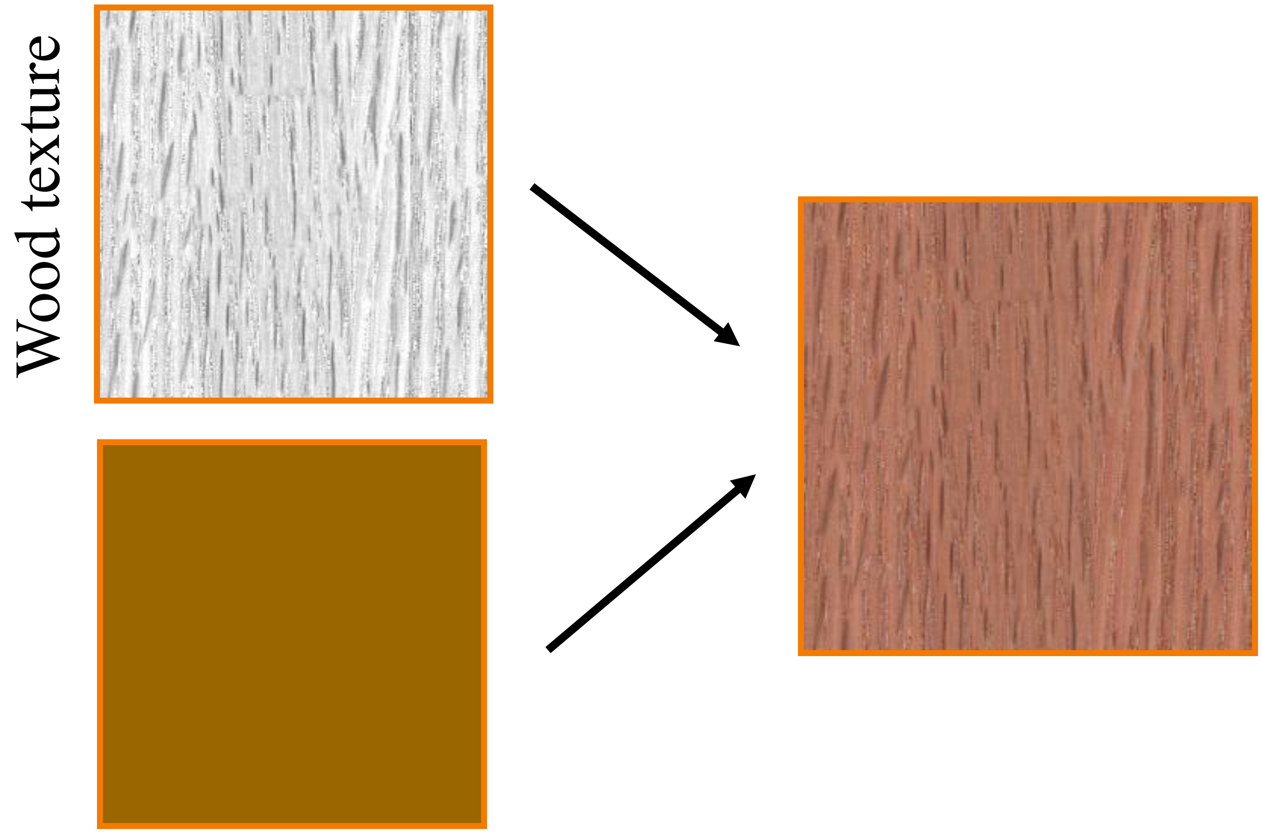
Modulation textures

Texture values scale result of lighting calculation



Texture value

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

Illumination Mapping

Map texture values to surface material parameter

- K_A
- K_D
- K_S
- K_T
- n

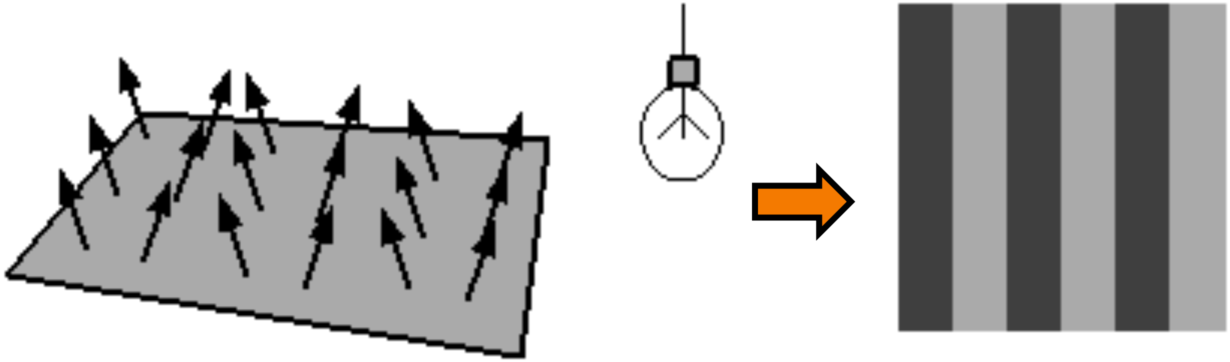
Texture value

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

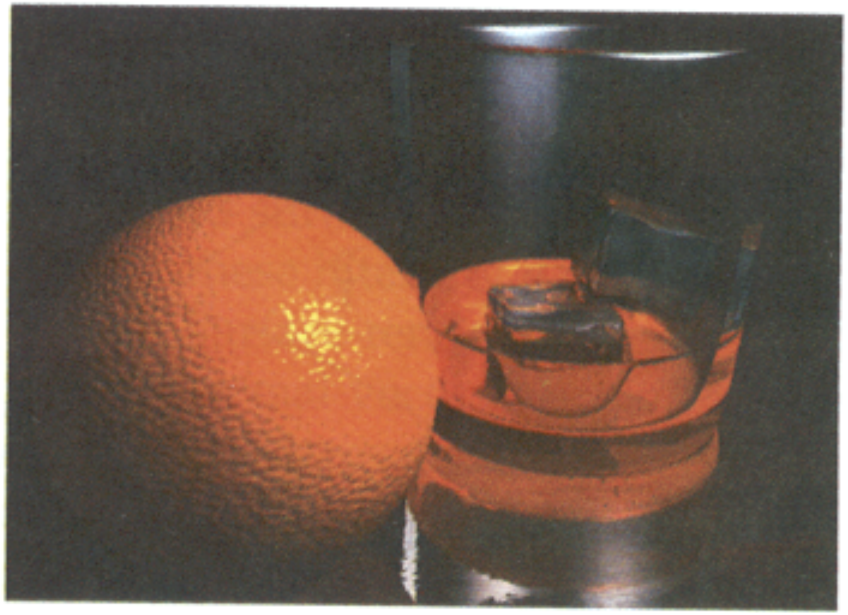
Bump/Normal Mapping

Texture values perturb surface normals:

- Use gradient of grayscale image (“bump”)
- Encode normals (or offsets) in RGB
- Encode normal offsets in tangent space

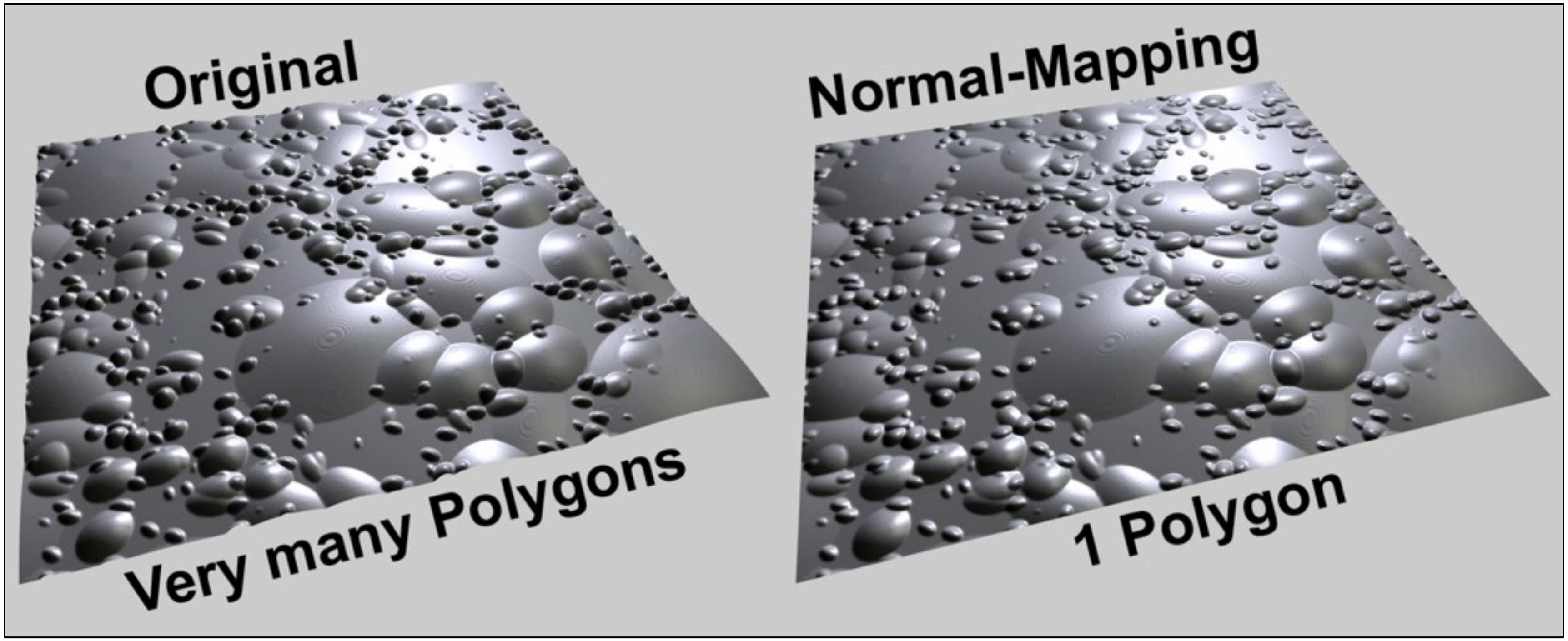


Bump Mapping



H&B Figure 14.100

Normal Mapping

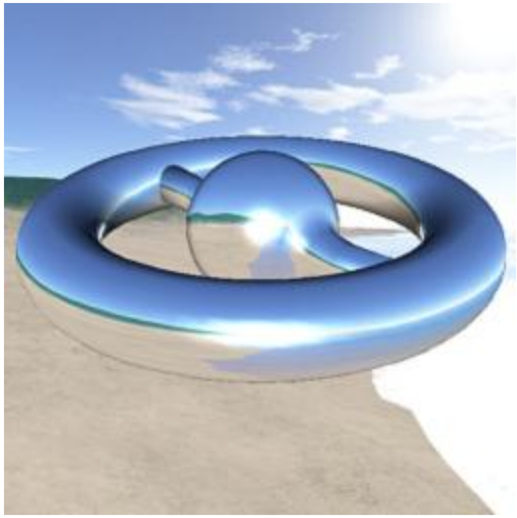


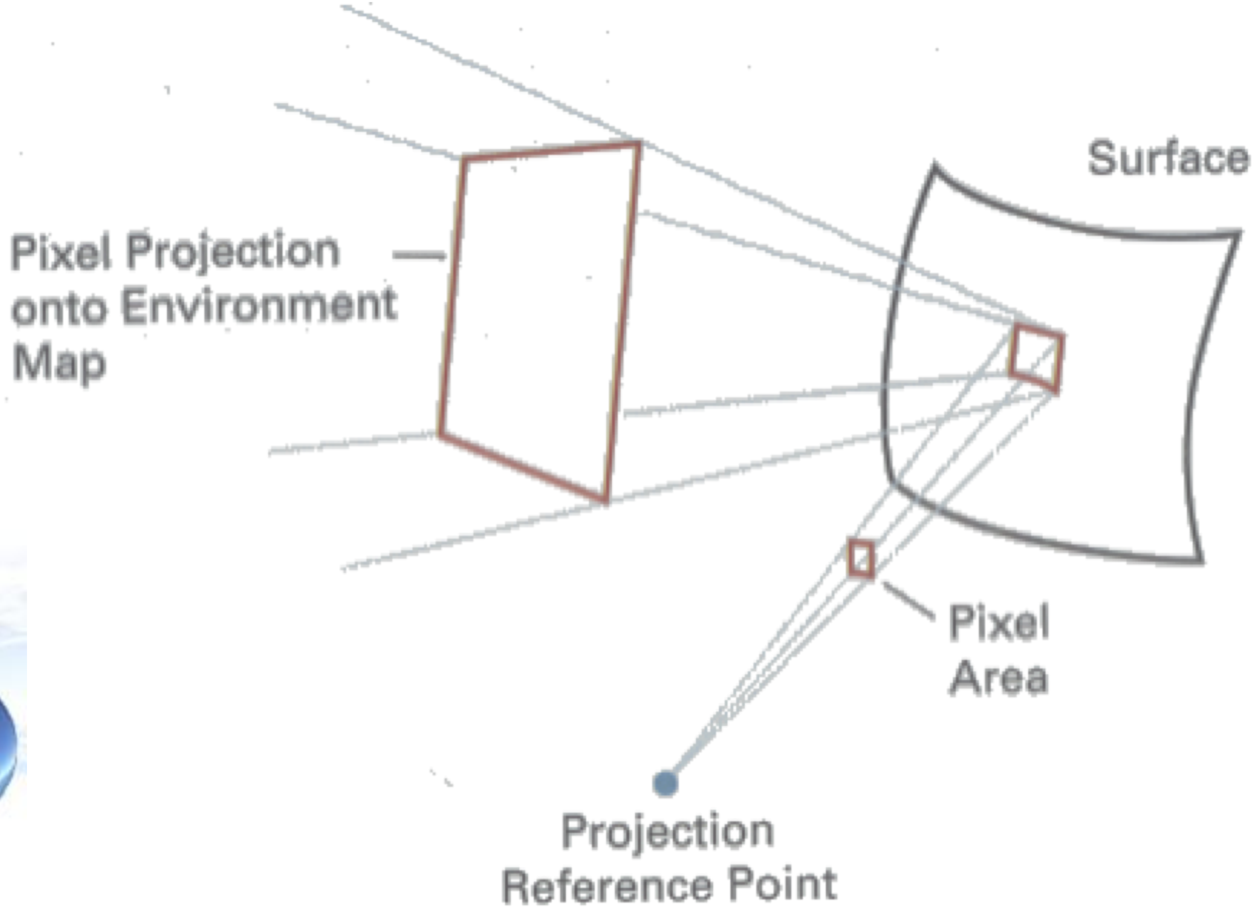
Graphisoft.com

Environment Mapping

Texture values are reflected off surface patch

Gamer3D/Wikipedia

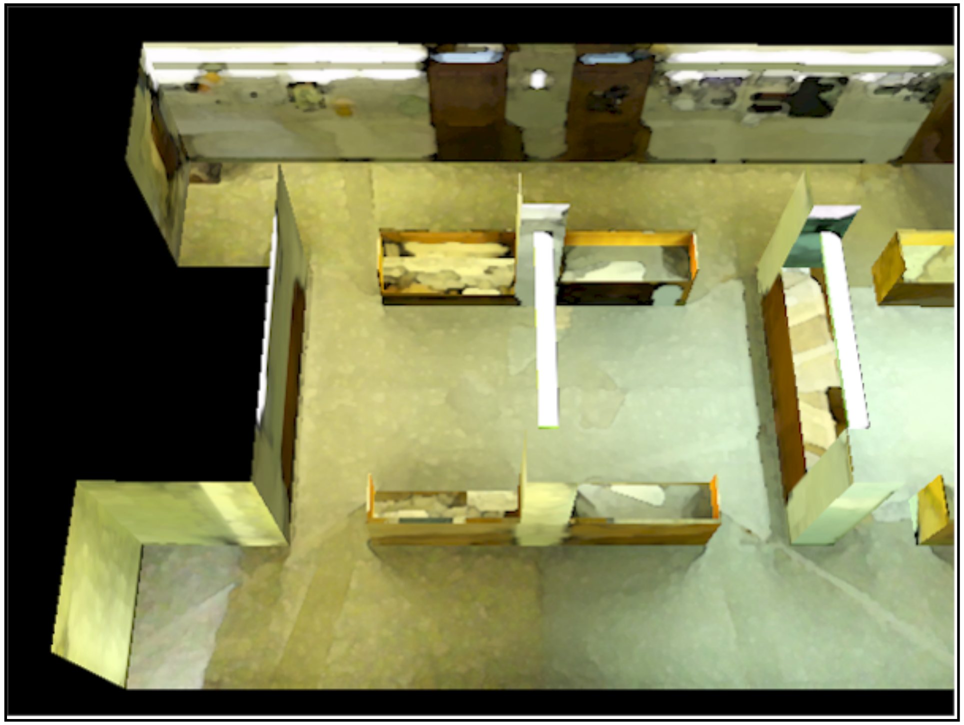




H&B Figure 14.93

Image-Based Rendering

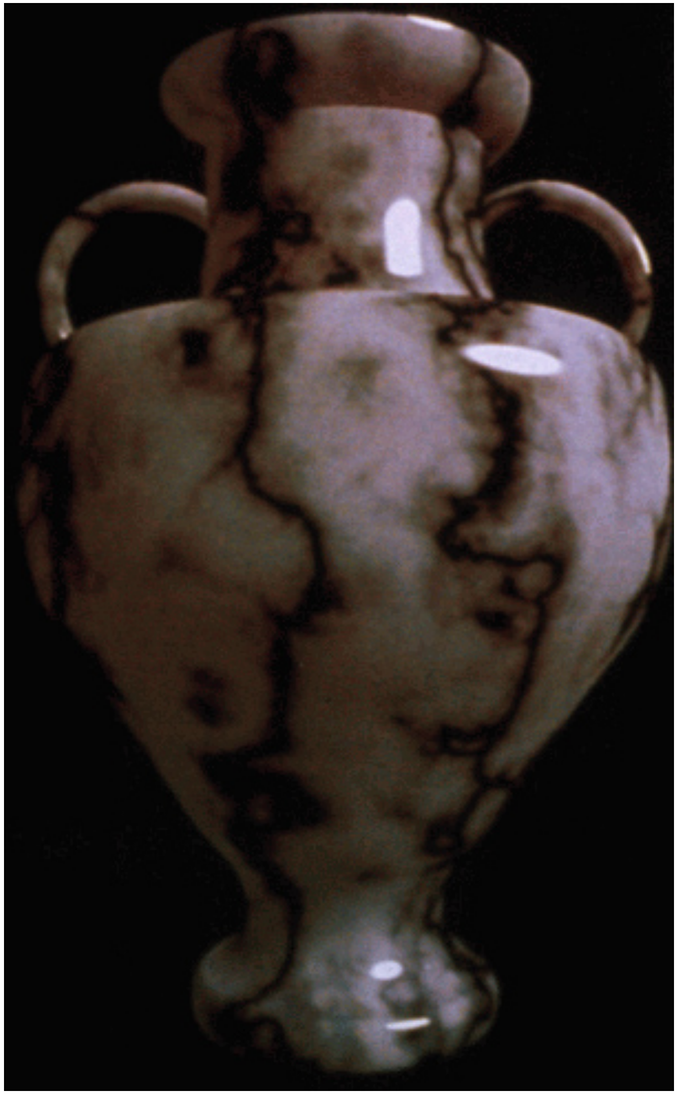
Map photographic textures to provide details for coarsely detailed polygonal model



Solid textures

Texture values indexed by 3D location (x,y,z)

- Expensive storage, or
- Compute on the fly, e.g. Perlin noise →



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    - Image-based rendering
    - Volume textures

Rasterization

- Scan conversion
  - Determine which pixels to fill
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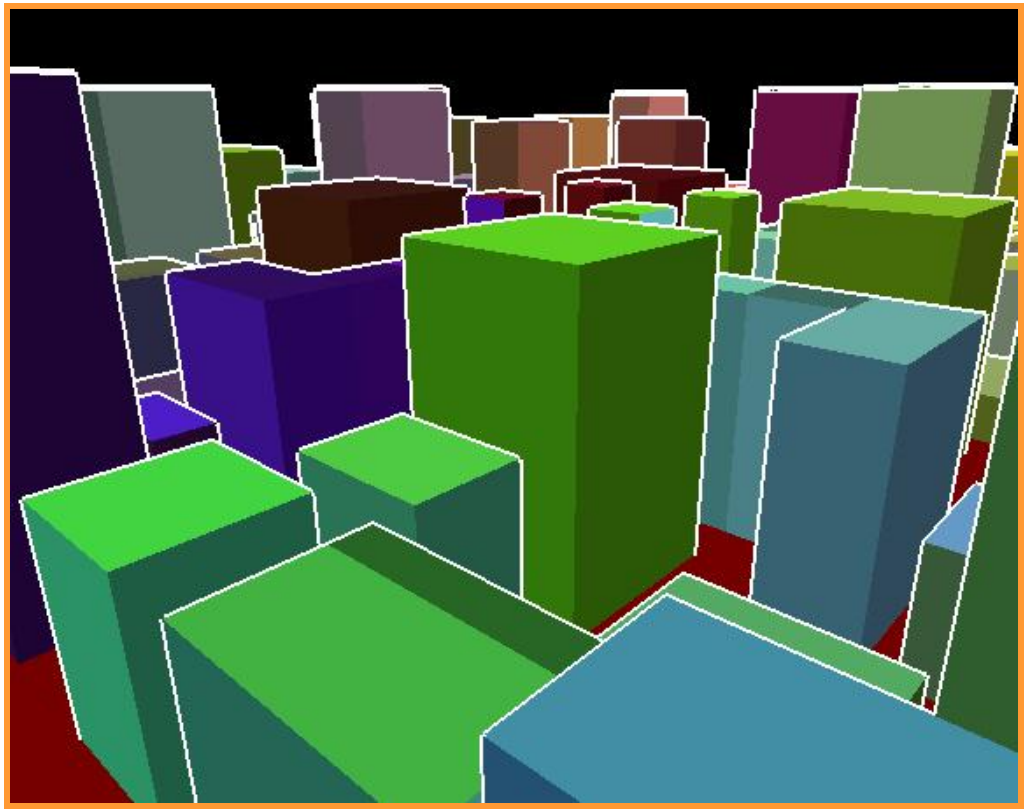
  - Describe shading variation within polygon interiors
- ➢ Visible surface determination
  - Figure out which surface is front-most at every pixel

Visible Surface Determination

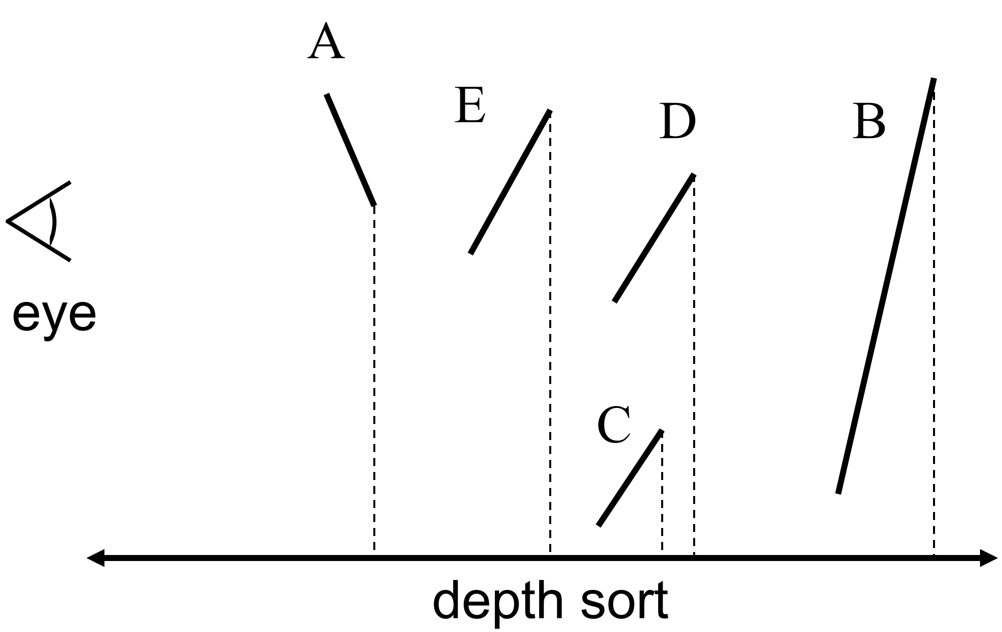
Make sure only front-most surface contributes to color at every pixel



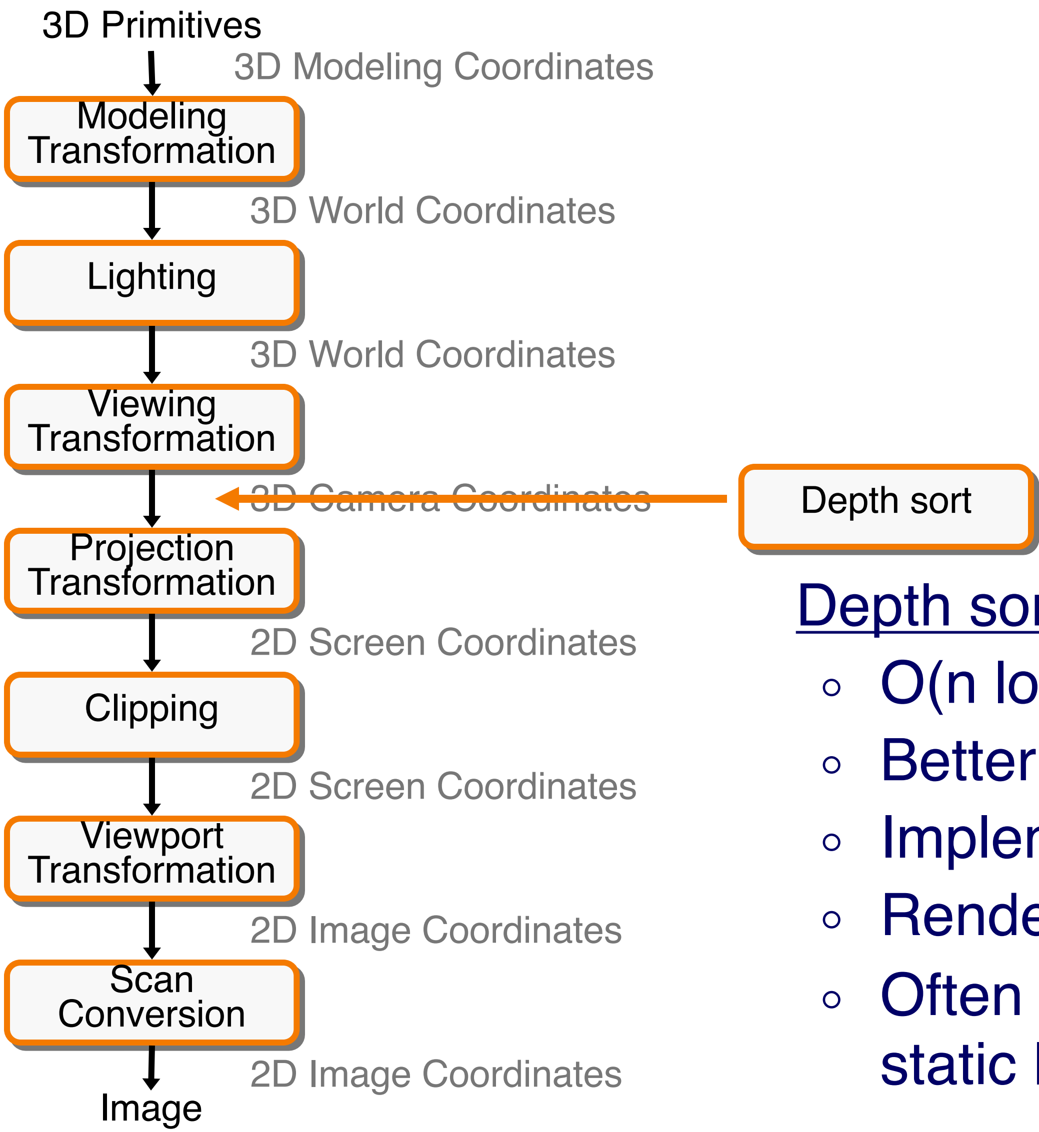
Depth sort

"Painter's algorithm"

- Sort surfaces in order of decreasing maximum depth
- Scan convert surfaces in back-to-front order, overwriting pixels



3D Rendering Pipeline



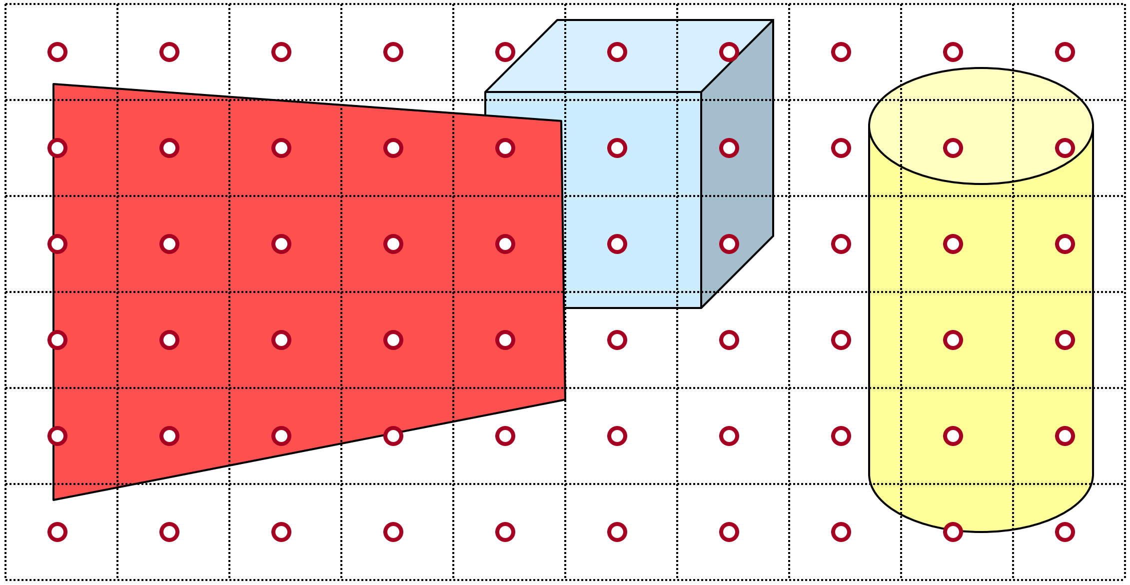
Depth sort comments

- O(n log n)
- Better with frame coherence?
- Implemented in software
- Render every polygon
- Often use BSP-tree or static list ordering

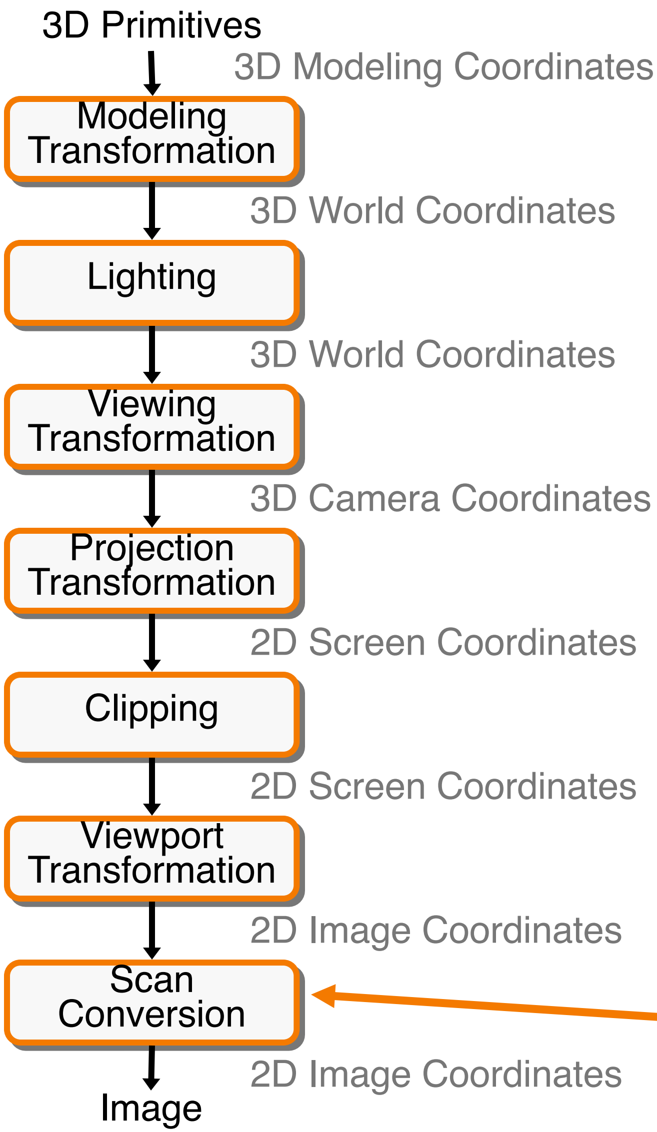
Z-Buffer

Maintain color & depth of closest object per pixel

- Framebuffer now RGBAz – initialize z to far plane
- Update only pixels with depth closer than in z-buffer
- Depths are interpolated from vertices, just like colors

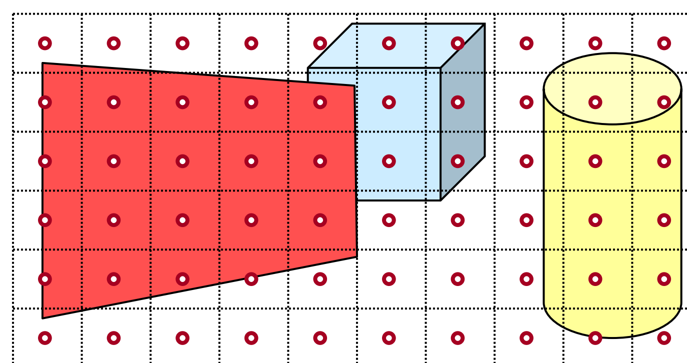


Z-Buffer



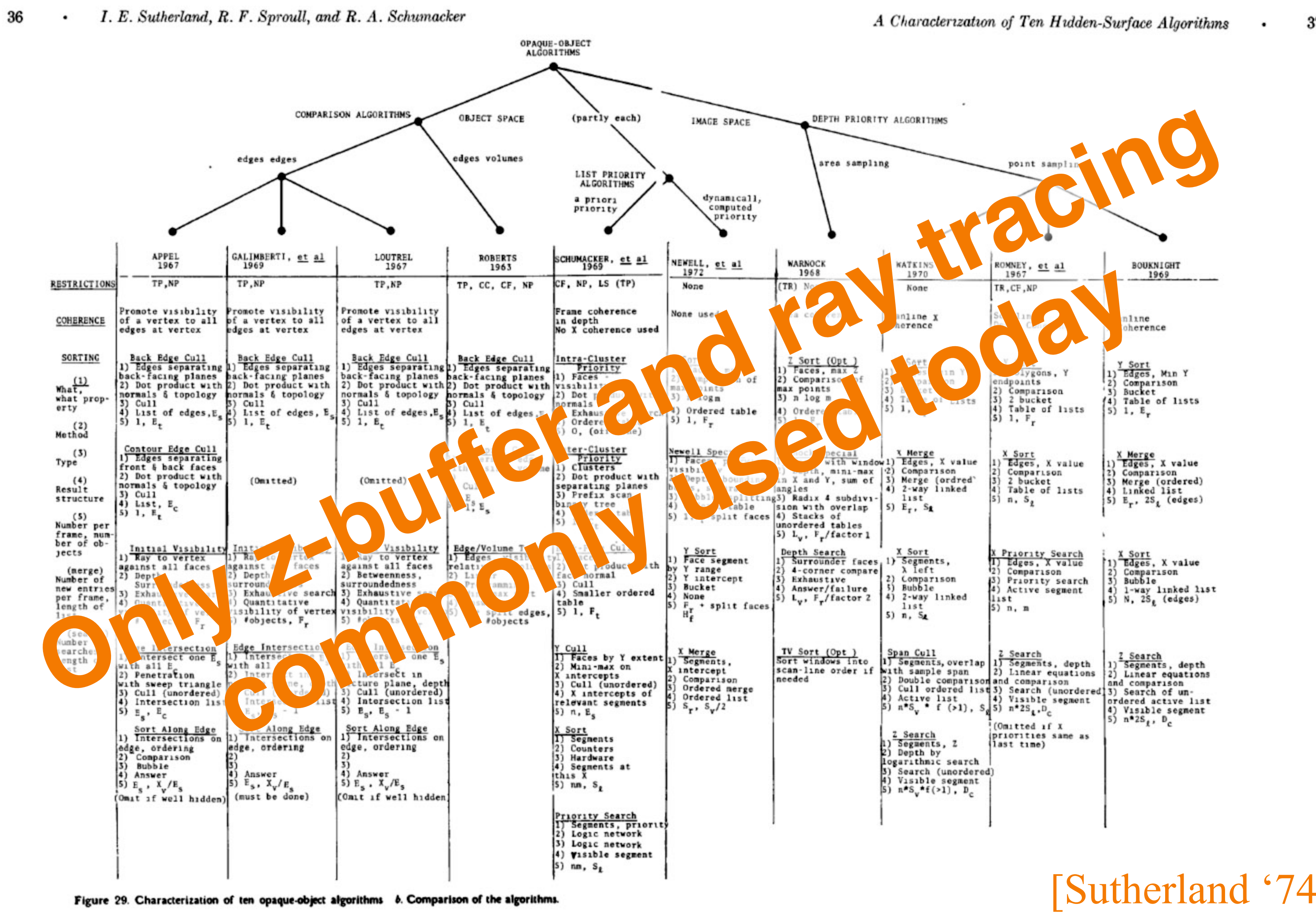
Z-buffer comments

+ Polygons rasterized in any order
+ Process one polygon at a time
+ Suitable for hardware pipeline
- Requires extra memory for z-buffer
- Subject to aliasing (A-buffer)
∘ Commonly in hardware



Z-Buffer

Hidden Surface Removal Algorithms



Only z-buffer and ray tracing commonly used today

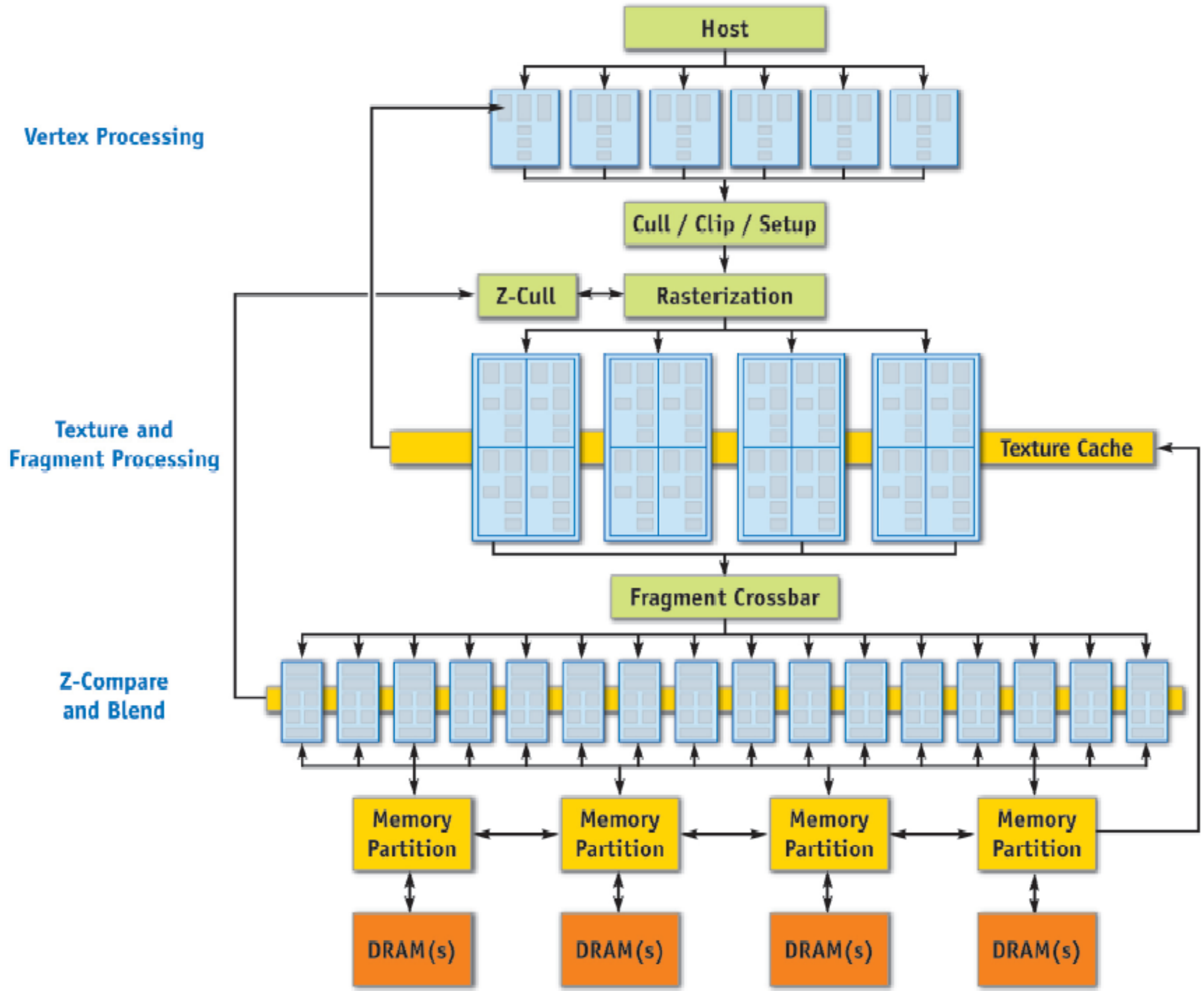
[Sutherland '74]

Rasterization Summary

- Scan conversion
  - Sweep-line algorithm
- Shading algorithms
  - Flat, Gouraud
- Texture mapping
  - Mipmaps
- Visibiliity determination
  - Z-buffer

This is all in hardware

GPU Architecture

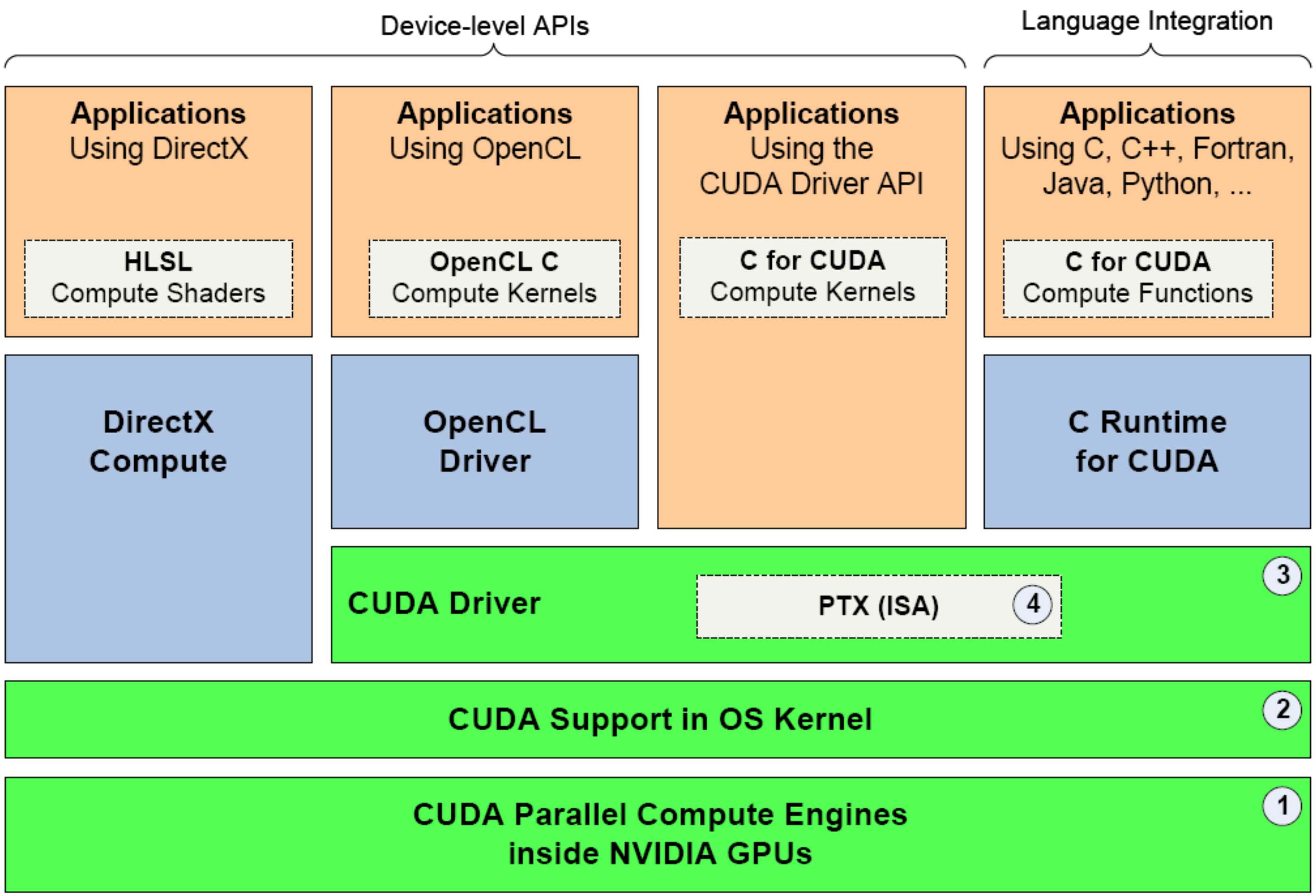


GeForce 6 Series Architecture

GPU Gems 2, NVIDIA

Actually …

- Graphics hardware is programmable



www.nvidia.com/cuda

Trend …

- GPU is general-purpose parallel computer

www.nvidia.com/cuda