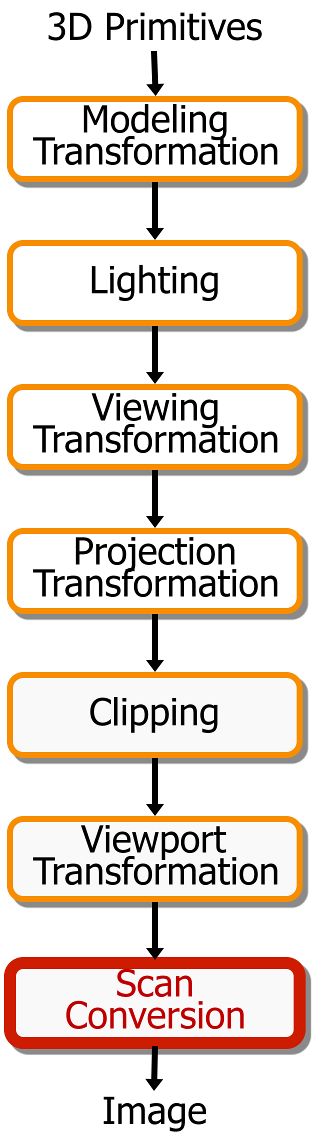
Rasterization

COS 426, Spring 2016

Princeton University

3D Rendering Pipeline (for direct illumination)



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
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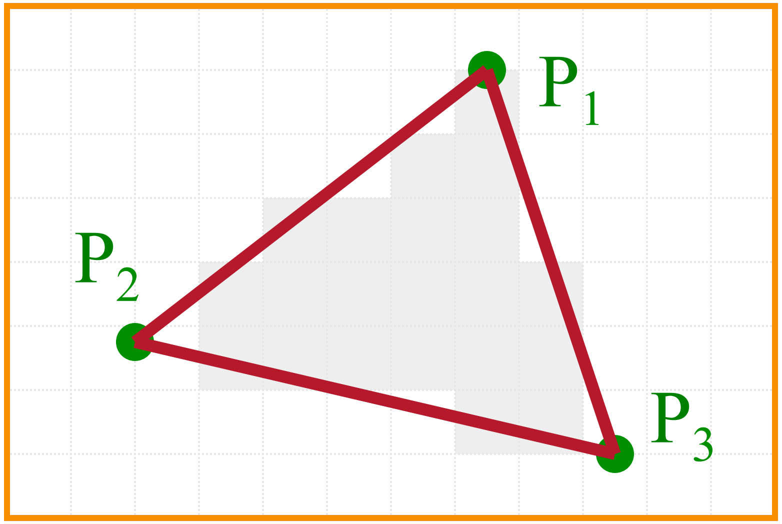
  - Figure out which surface is front-most at every pixel

Shading

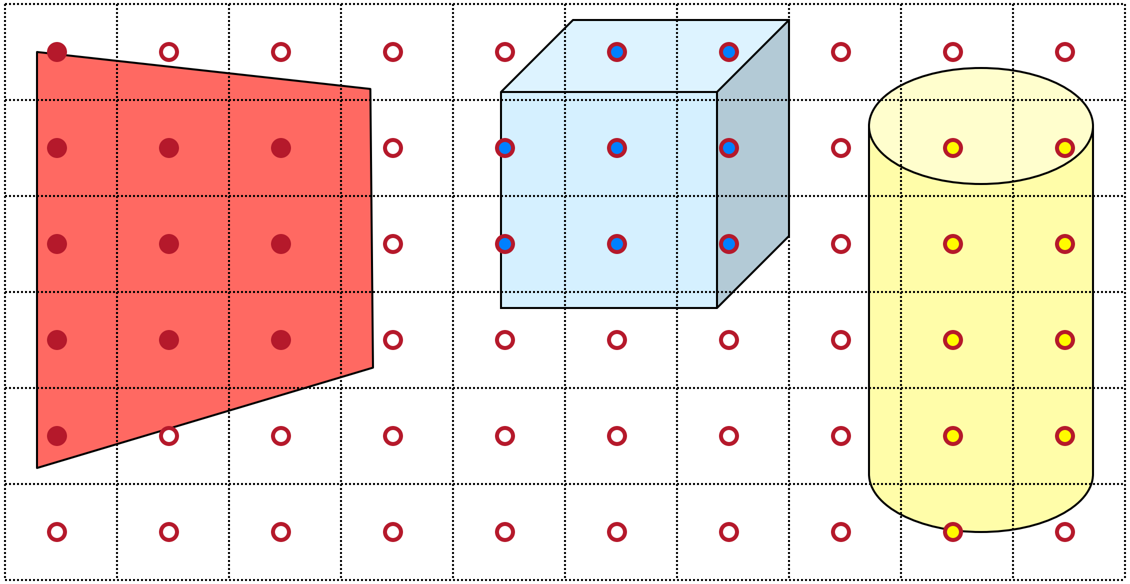
- How do we choose a color for each filled pixel?



Emphasis on methods that can be implemented in hardware

Ray Casting

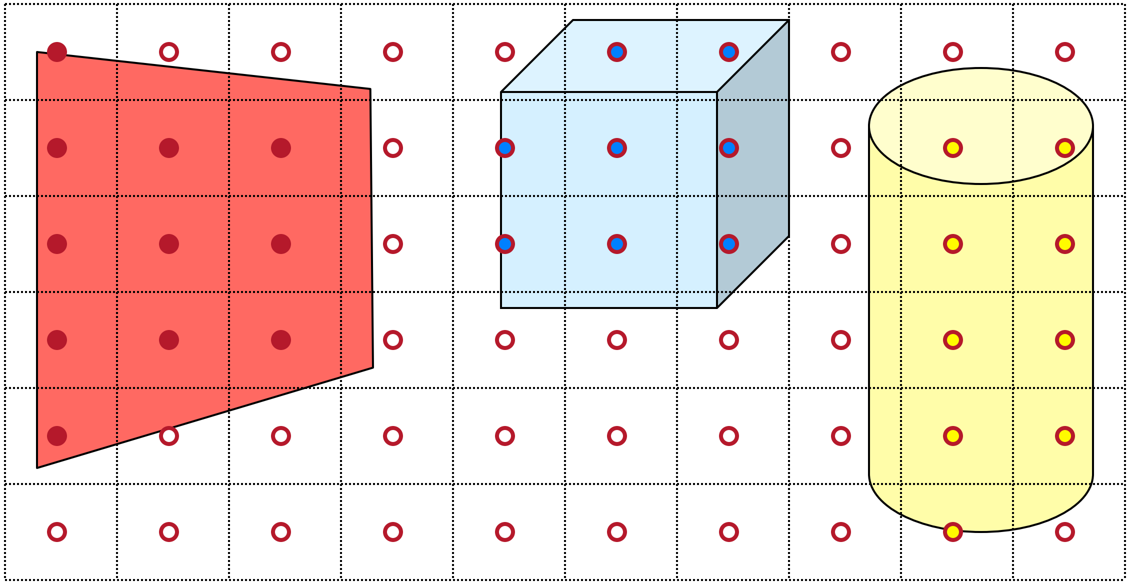
- Simplest shading approach is to perform independent lighting calculation for every pixel



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

Polygon Shading

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



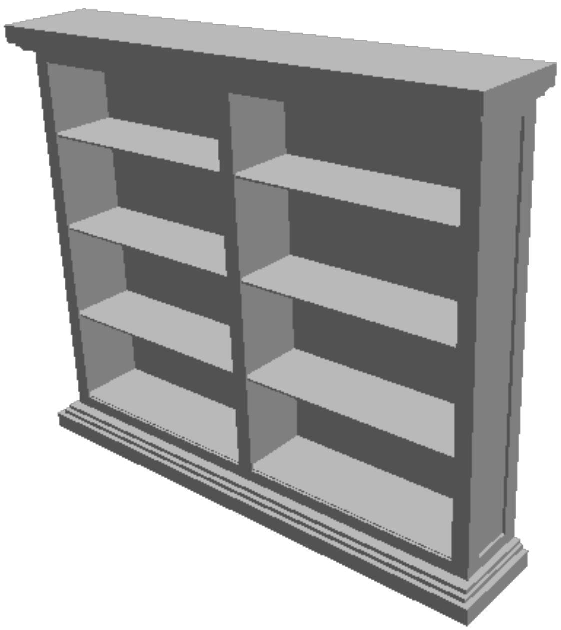
$$I = I_E + K_A I_{AL} + \sum_i \left(K_D (N \cdot L_i) I_i + K_S (V \cdot R_i)^n I_i \right)$$

Polygon Shading Algorithms

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

Flat Shading

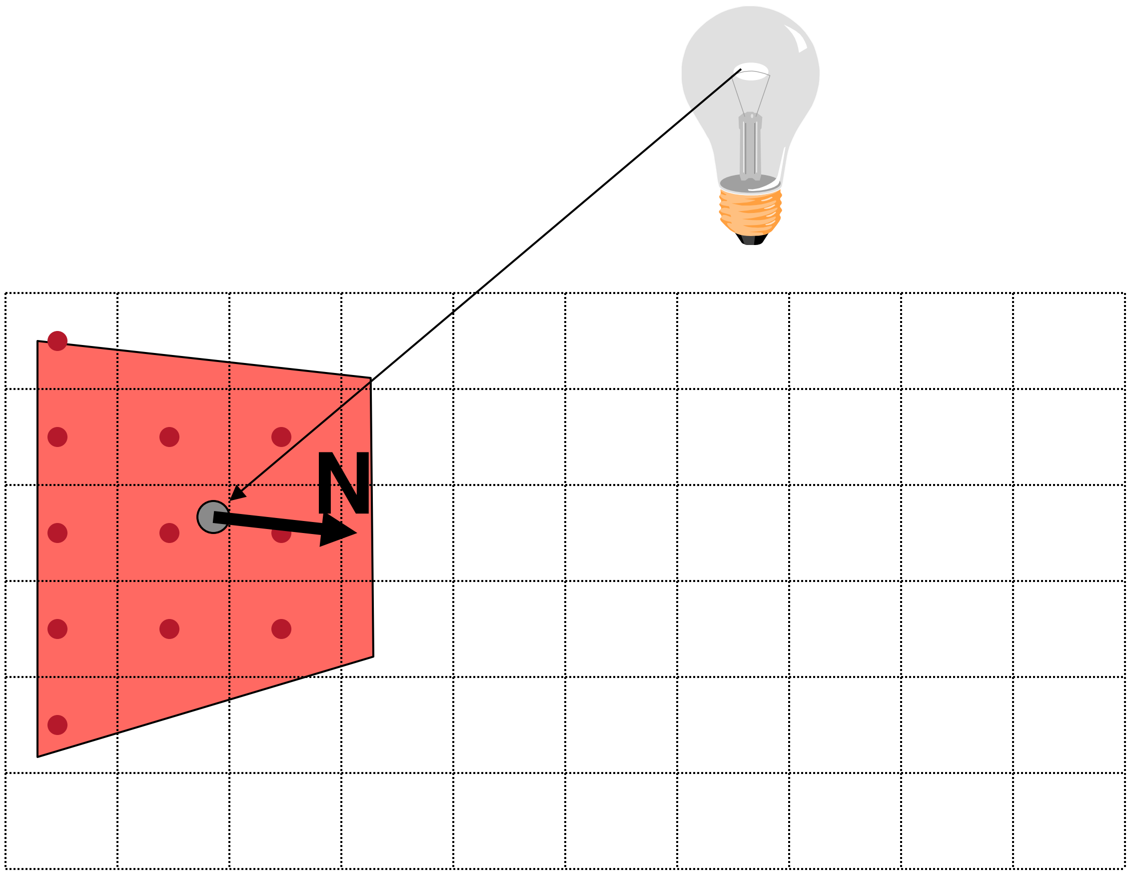
- What if a faceted object is illuminated only by directional light sources and is either diffuse or viewed from infinitely far away



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

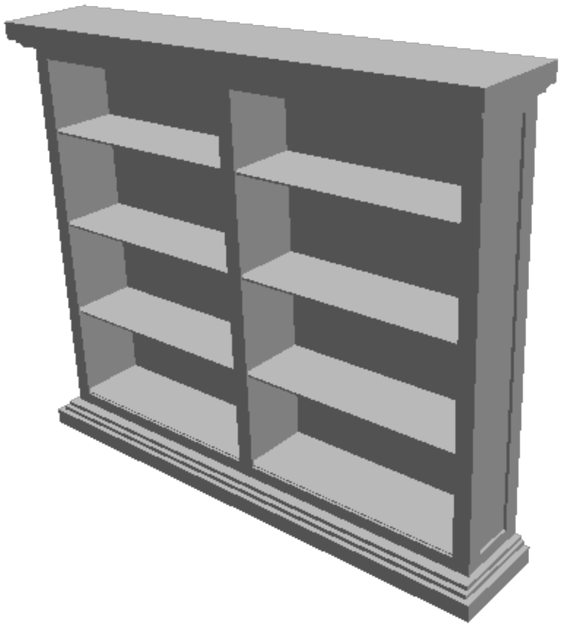
Flat Shading

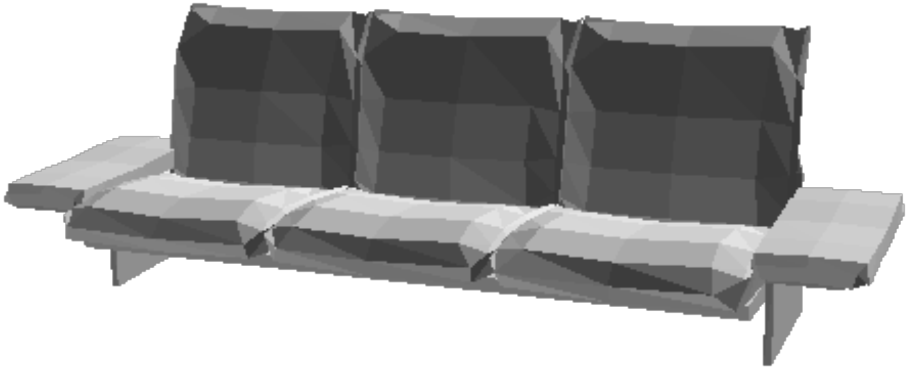
- One illumination calculation per polygon
  - Assign all pixels inside each polygon the same color



Flat Shading

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



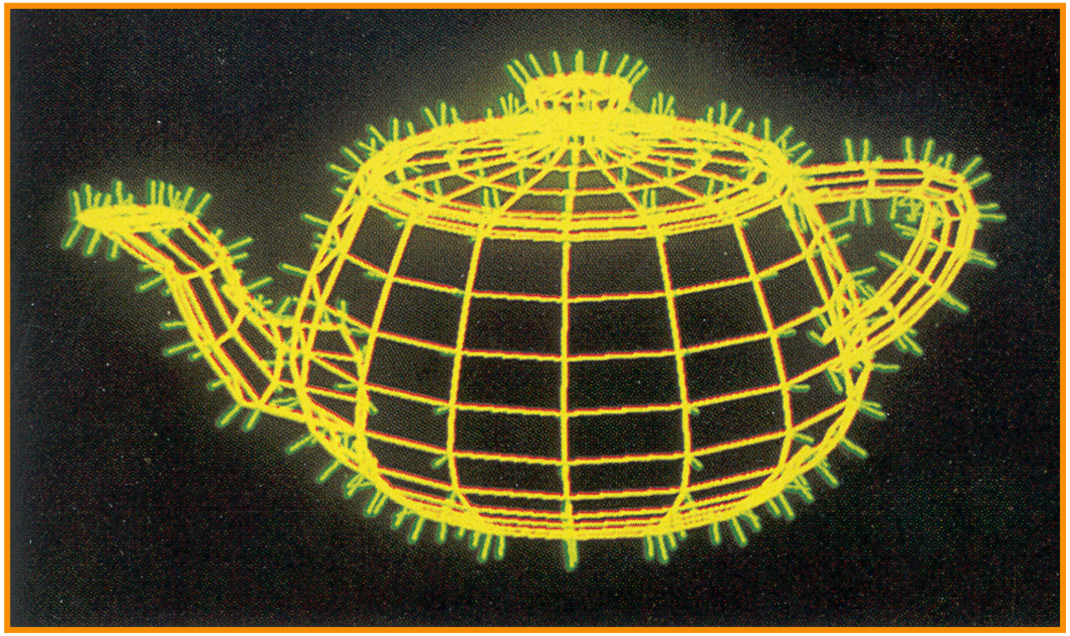


Polygon Shading Algorithms

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

Gouraud Shading

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

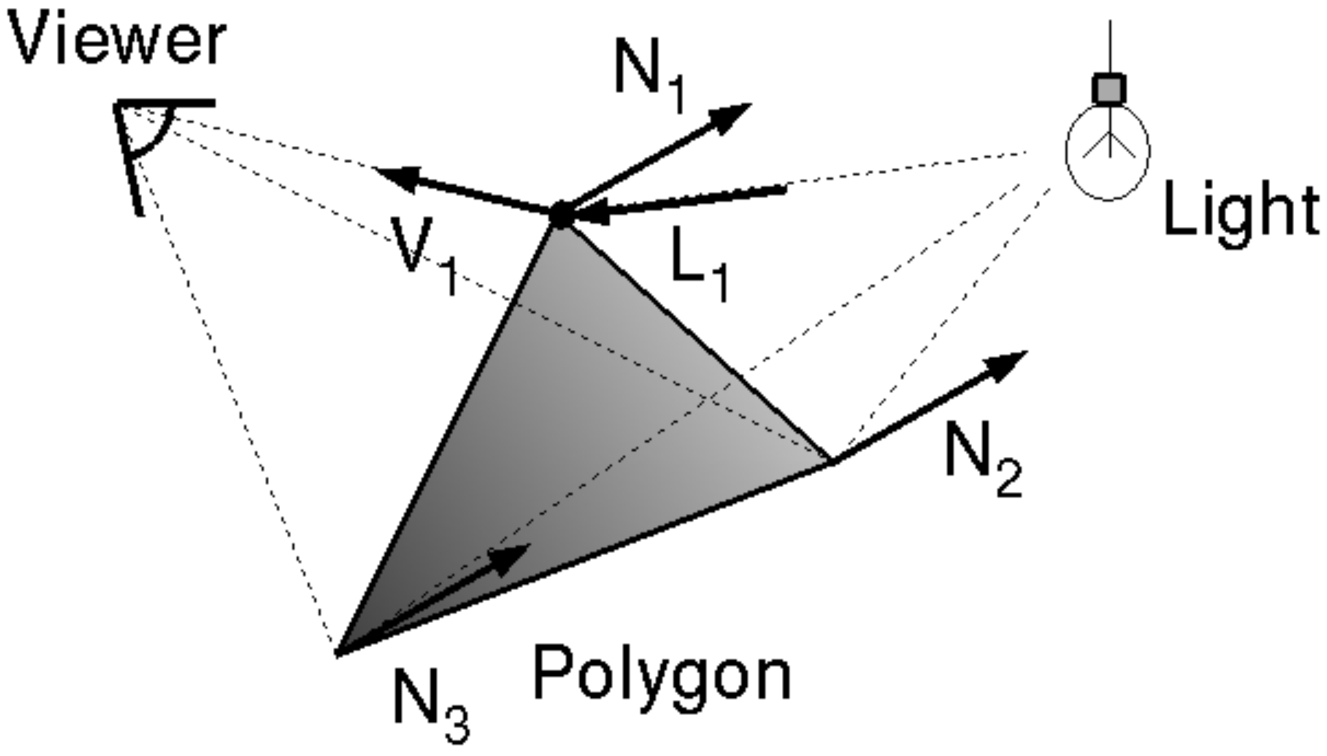


Watt Plate 7

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

Gouraud Shading

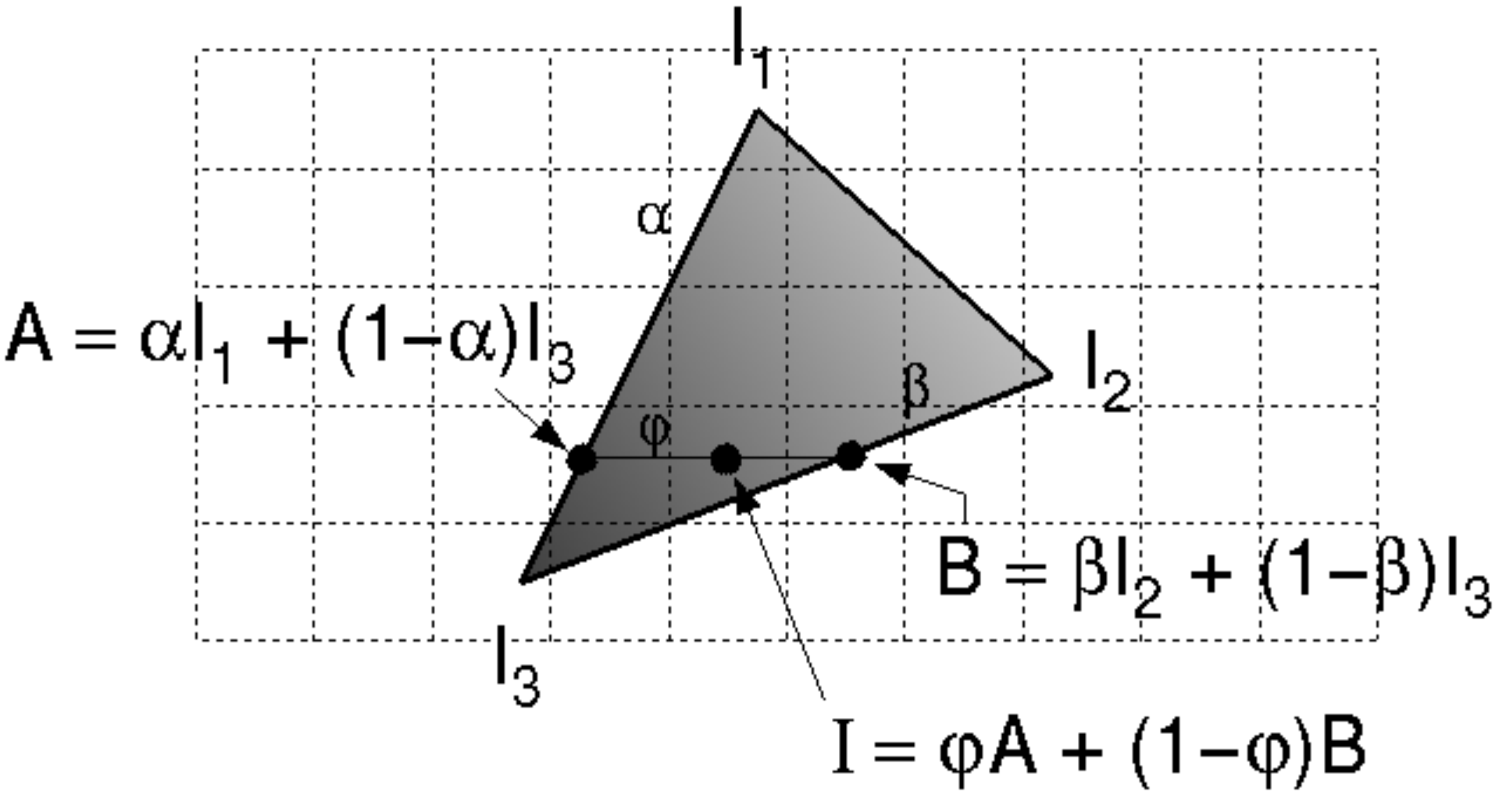
- Method 1: One lighting calculation per vertex
  - Assign pixels inside polygon by interpolating colors computed at vertices



Gouraud Shading

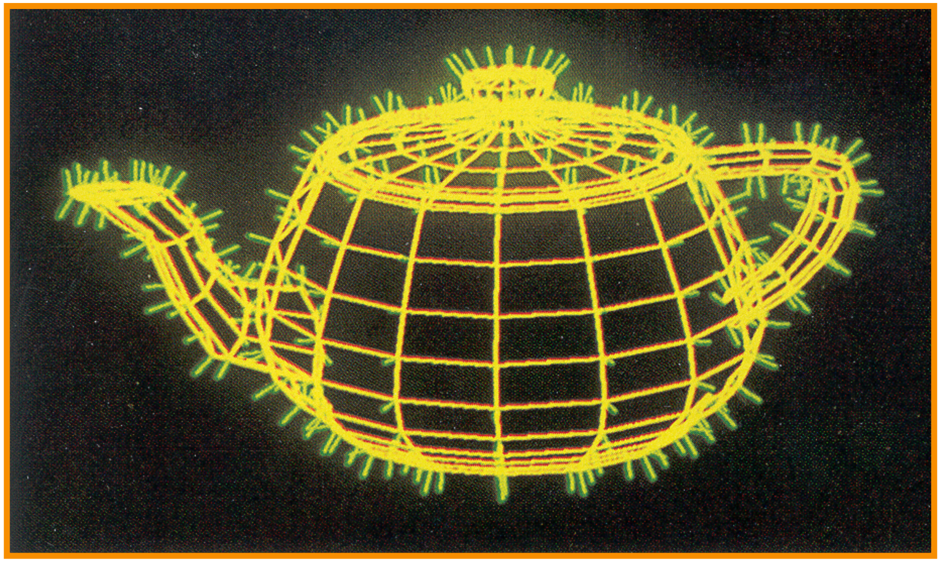
Bilinear interpolation of colors at vertices

- down and across scan lines = barycentric coords



Gouraud Shading

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

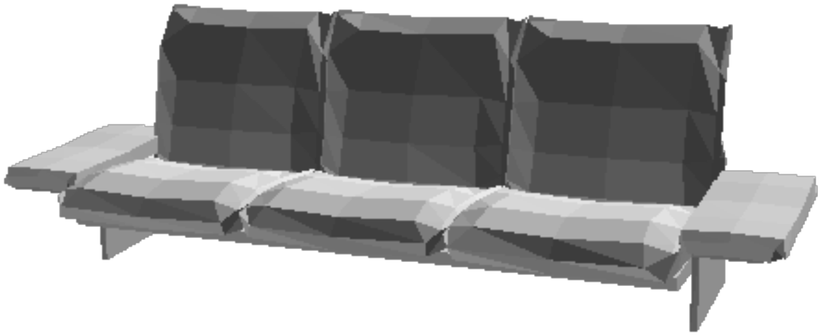


Mesh with shared normals at vertices

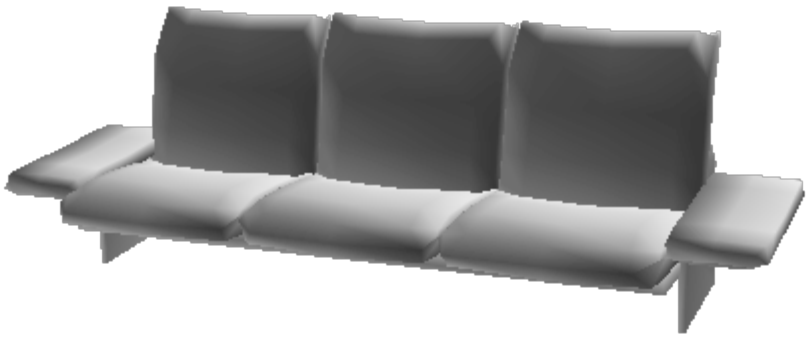
Watt Plate 7

Gouraud Shading

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



Flat Shading



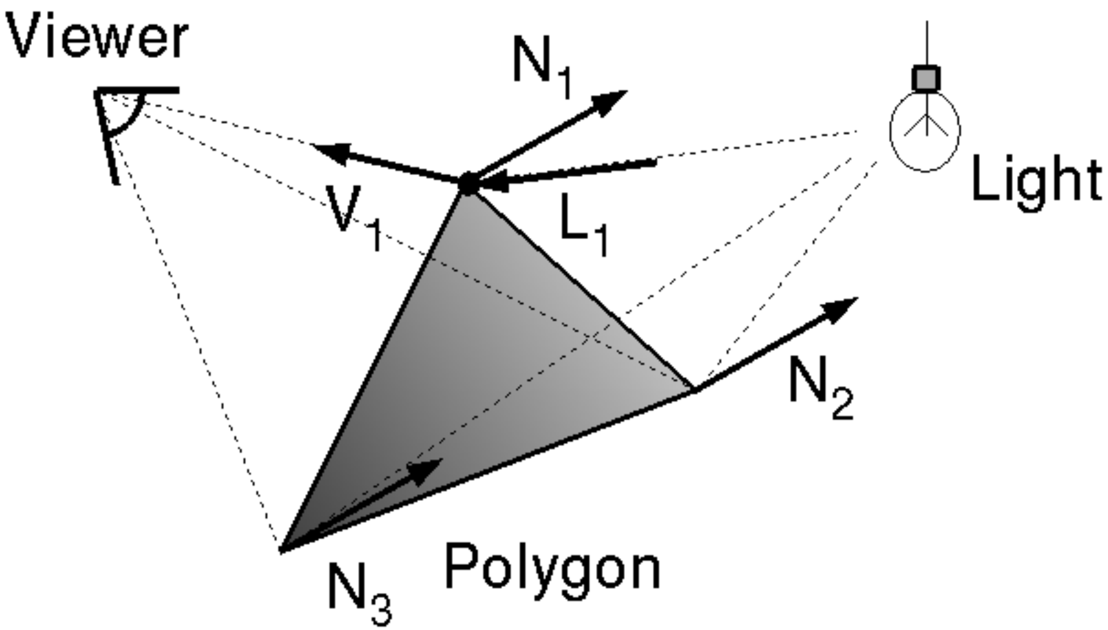
Gouraud Shading

Polygon Shading Algorithms

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

Phong Shading

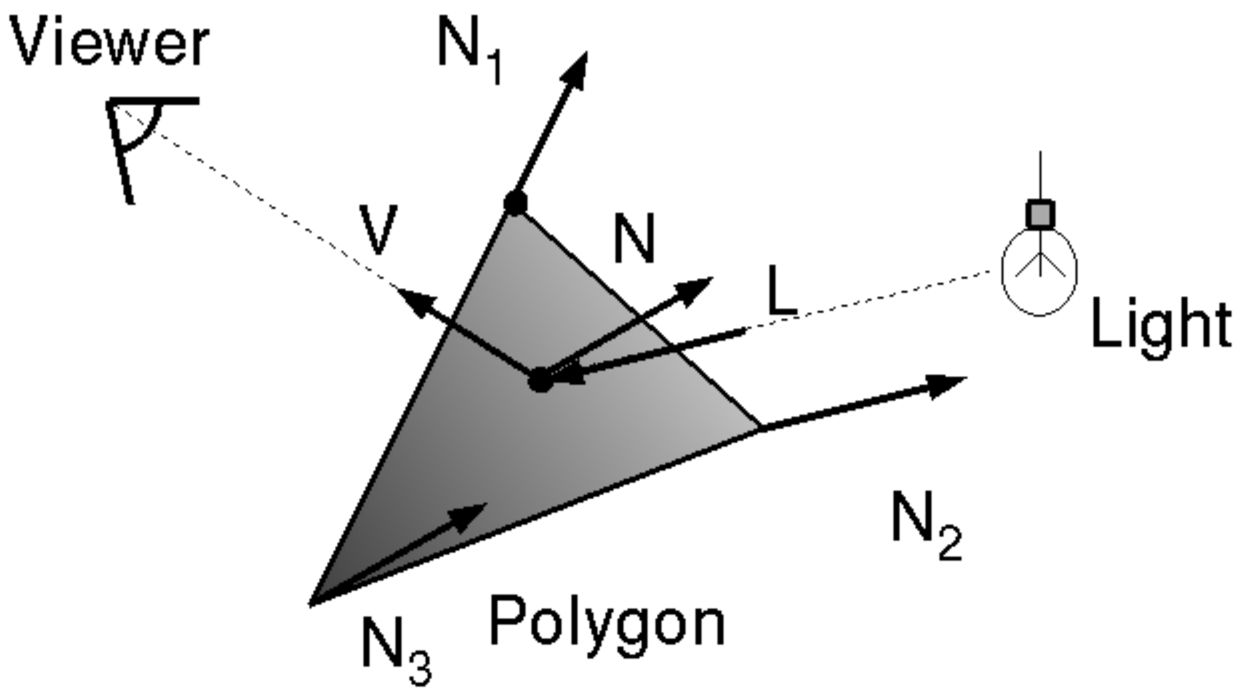
- What if polygonal mesh is too coarse to capture illumination effects in polygon interiors?



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

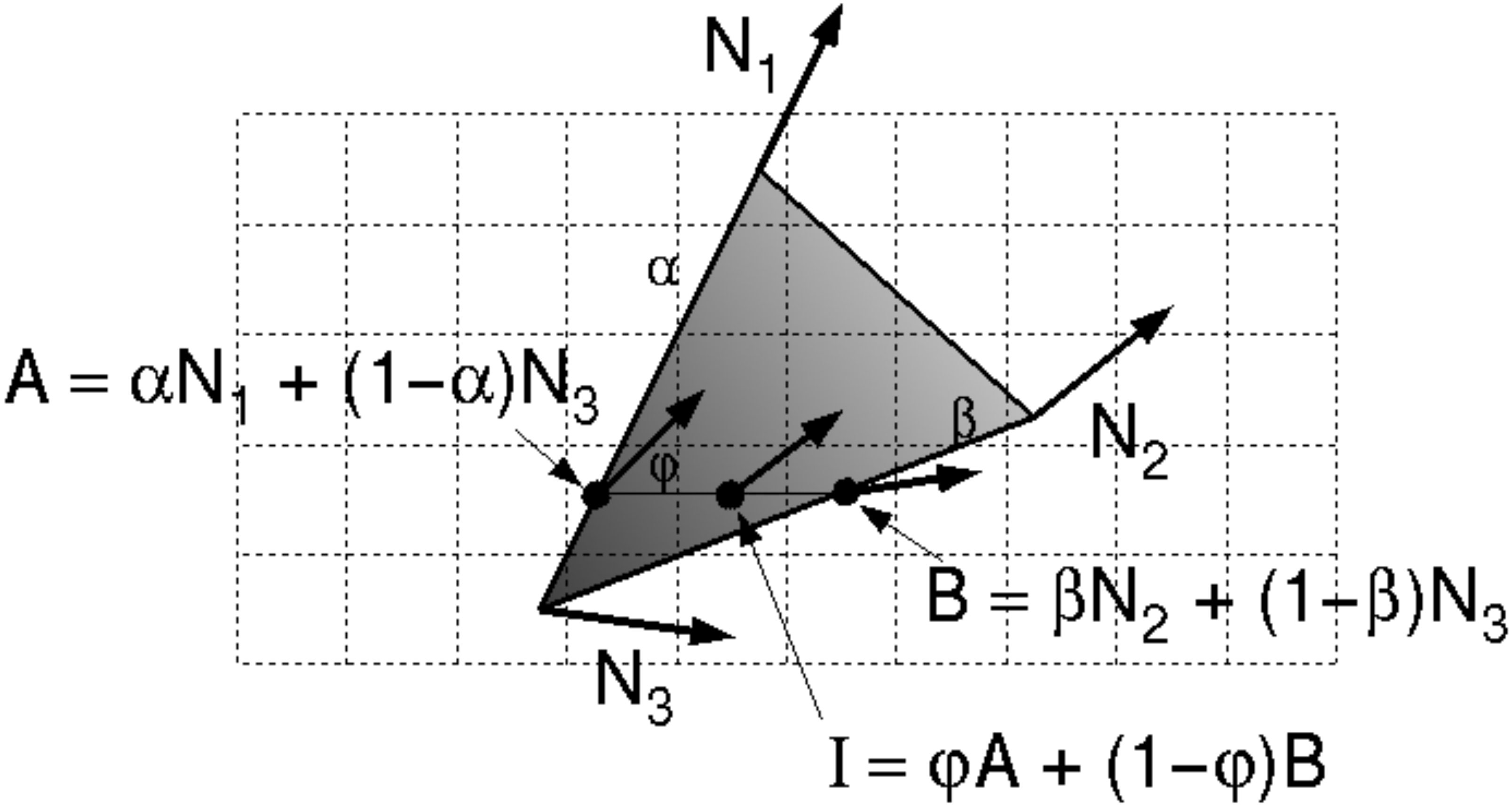
Phong Shading

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



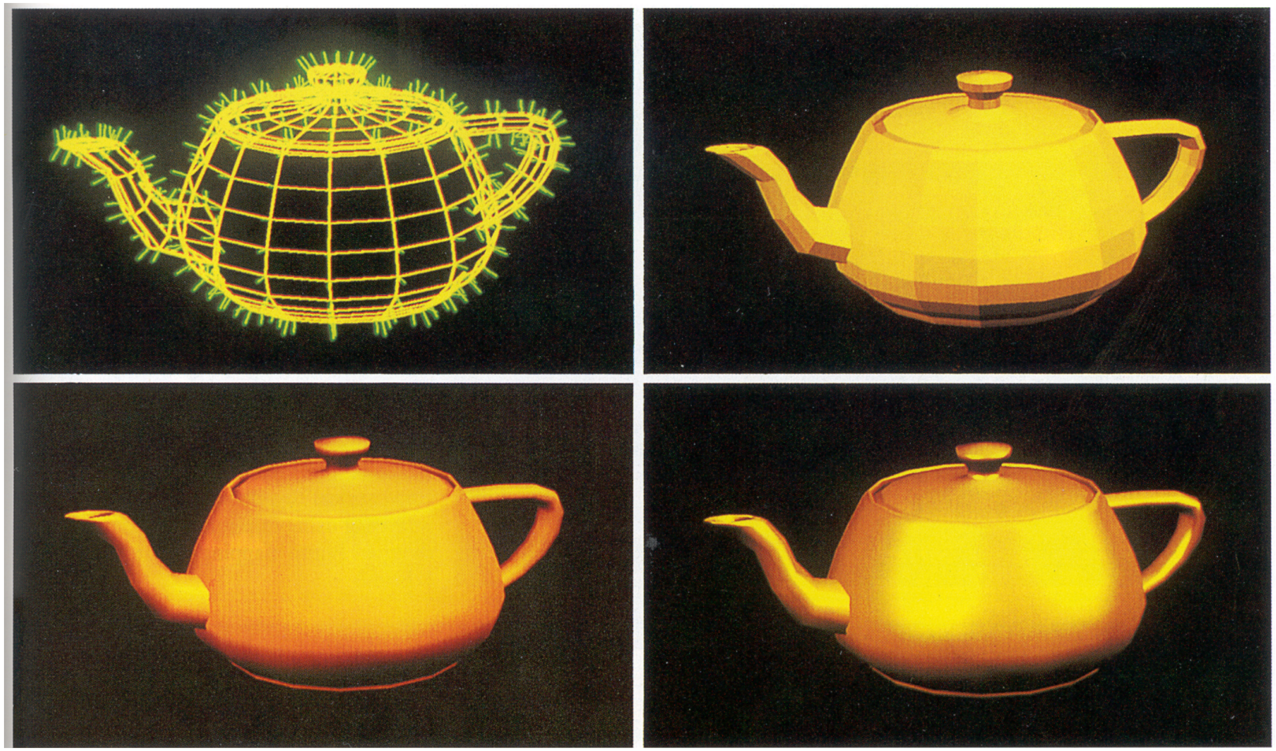
Phong Shading

Bilinear interpolation of surface normals at vertices



Polygon Shading Algorithms

Wireframe Flat

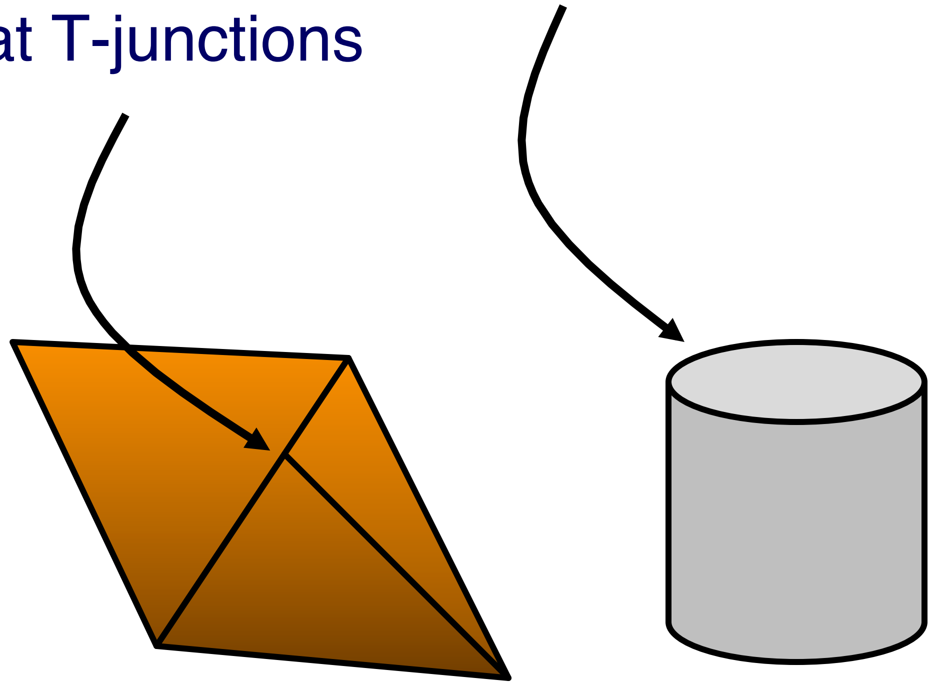


Gouraud Phong

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

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- ➢ Texture mapping
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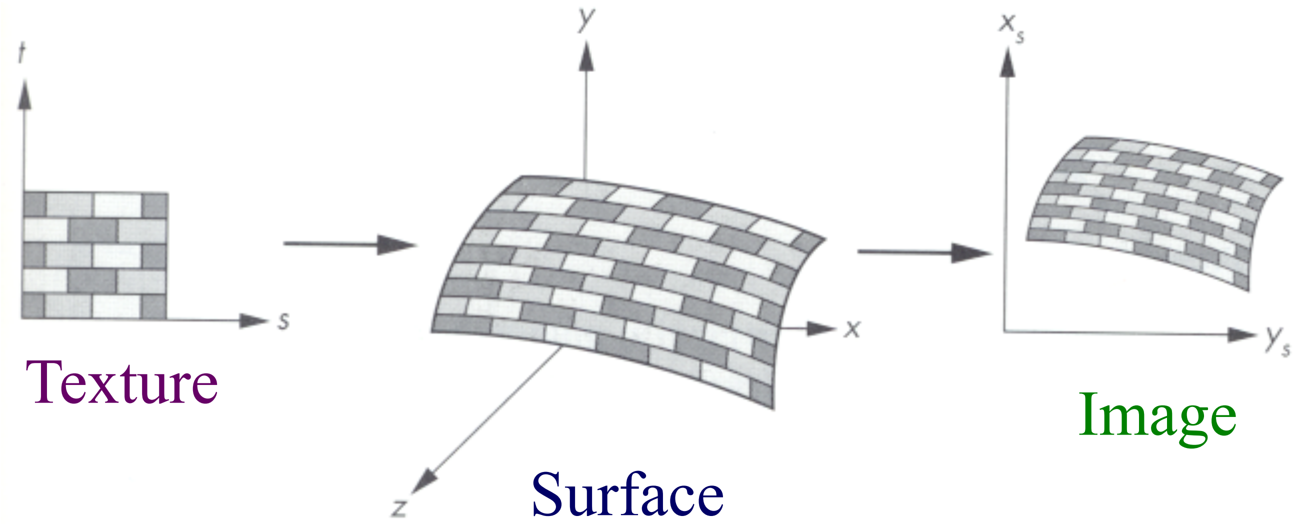
Textures

- 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

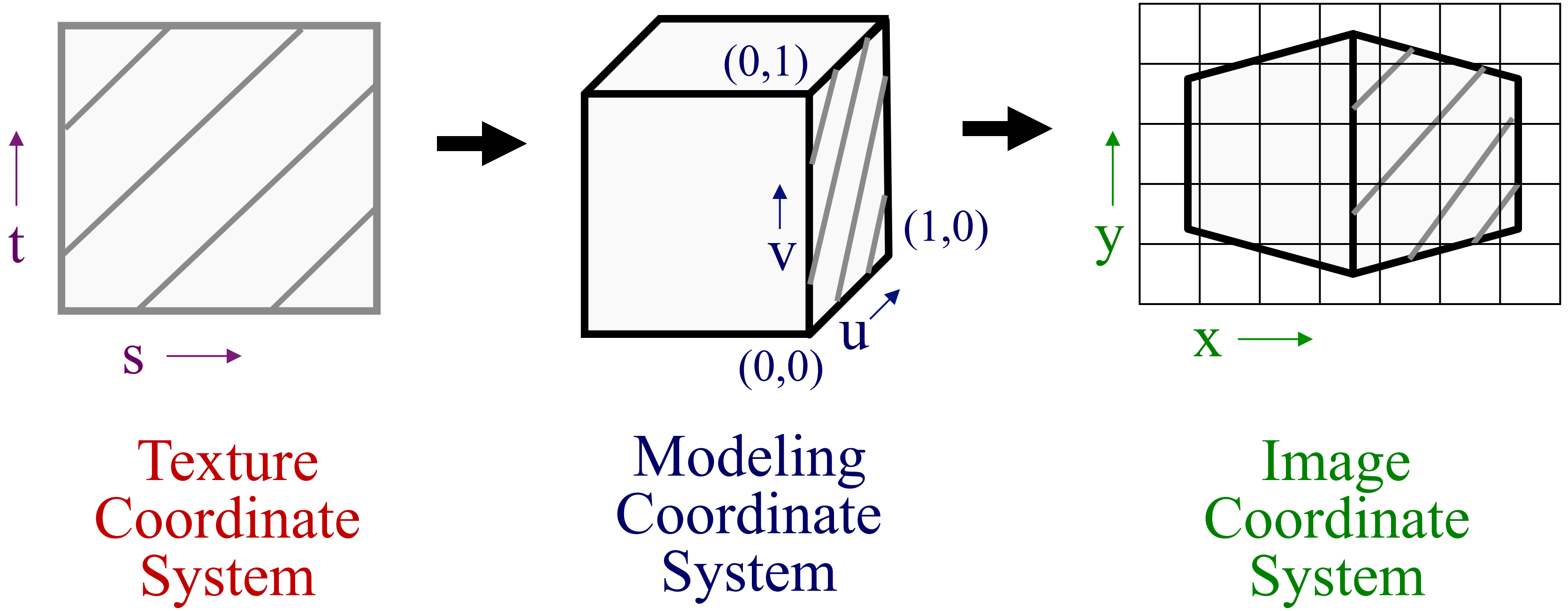
Textures

- Add visual detail to surfaces of 3D objects

[Daren Horley]

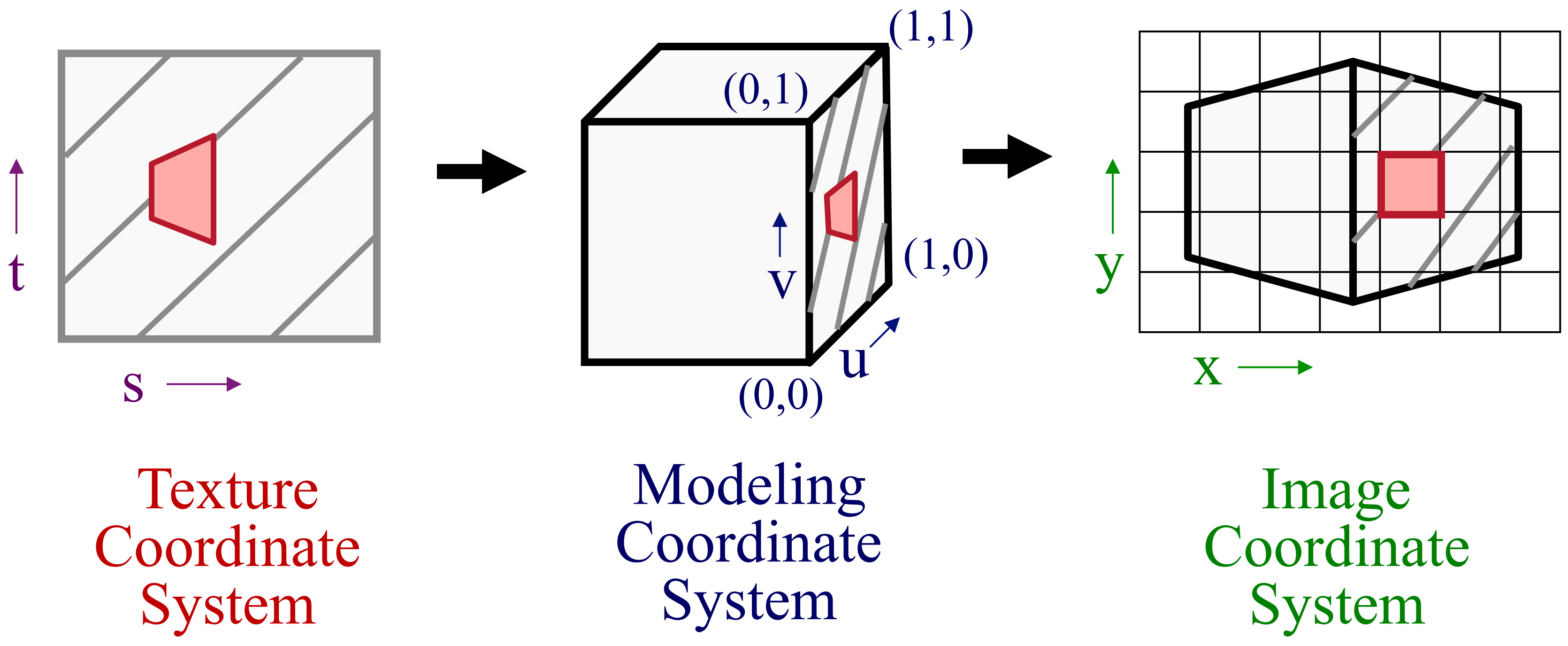
Texture Mapping

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



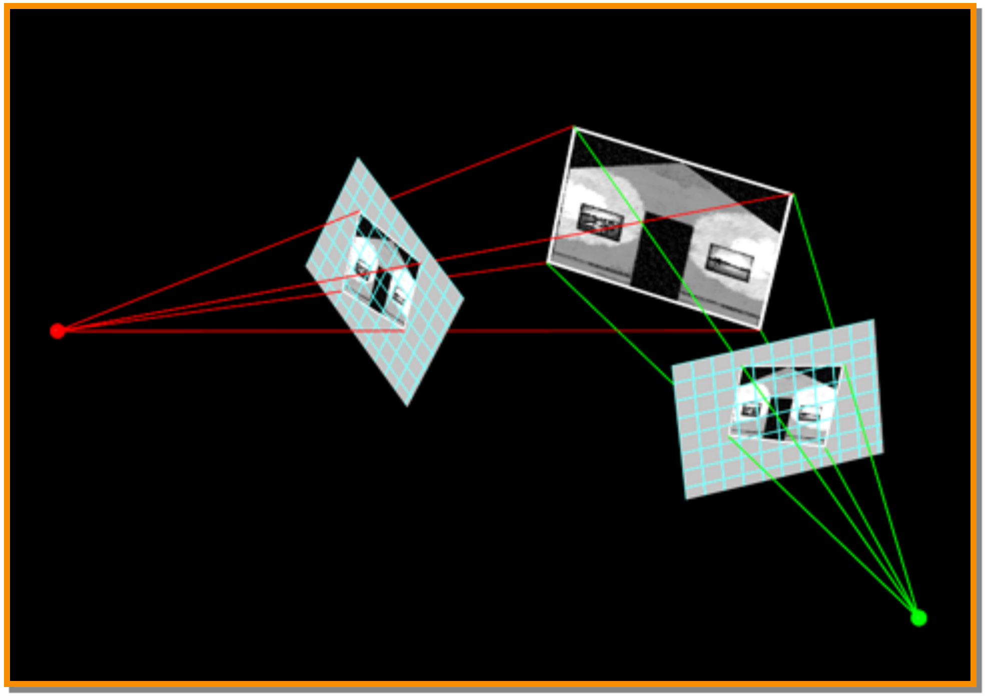
Texture Mapping

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



Texture Mapping

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



[Allison Klein]

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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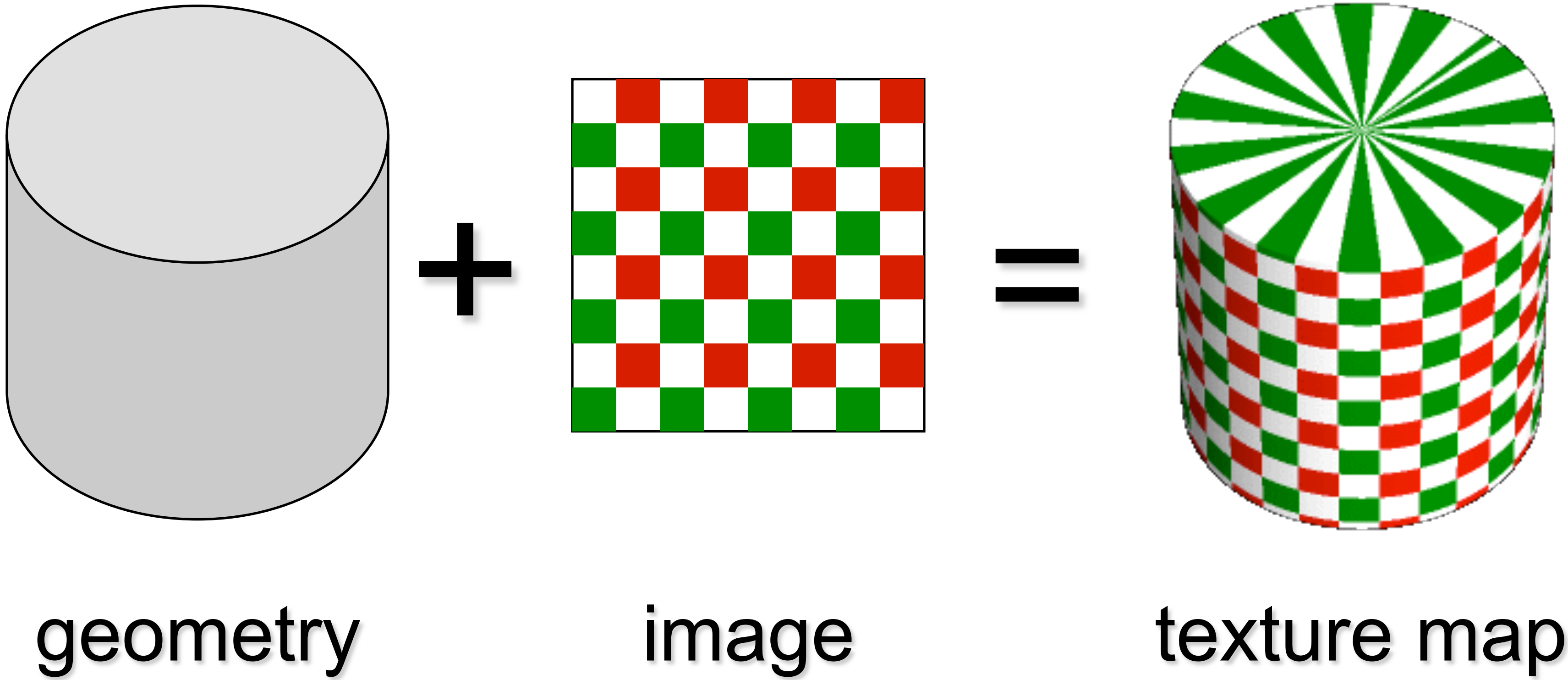
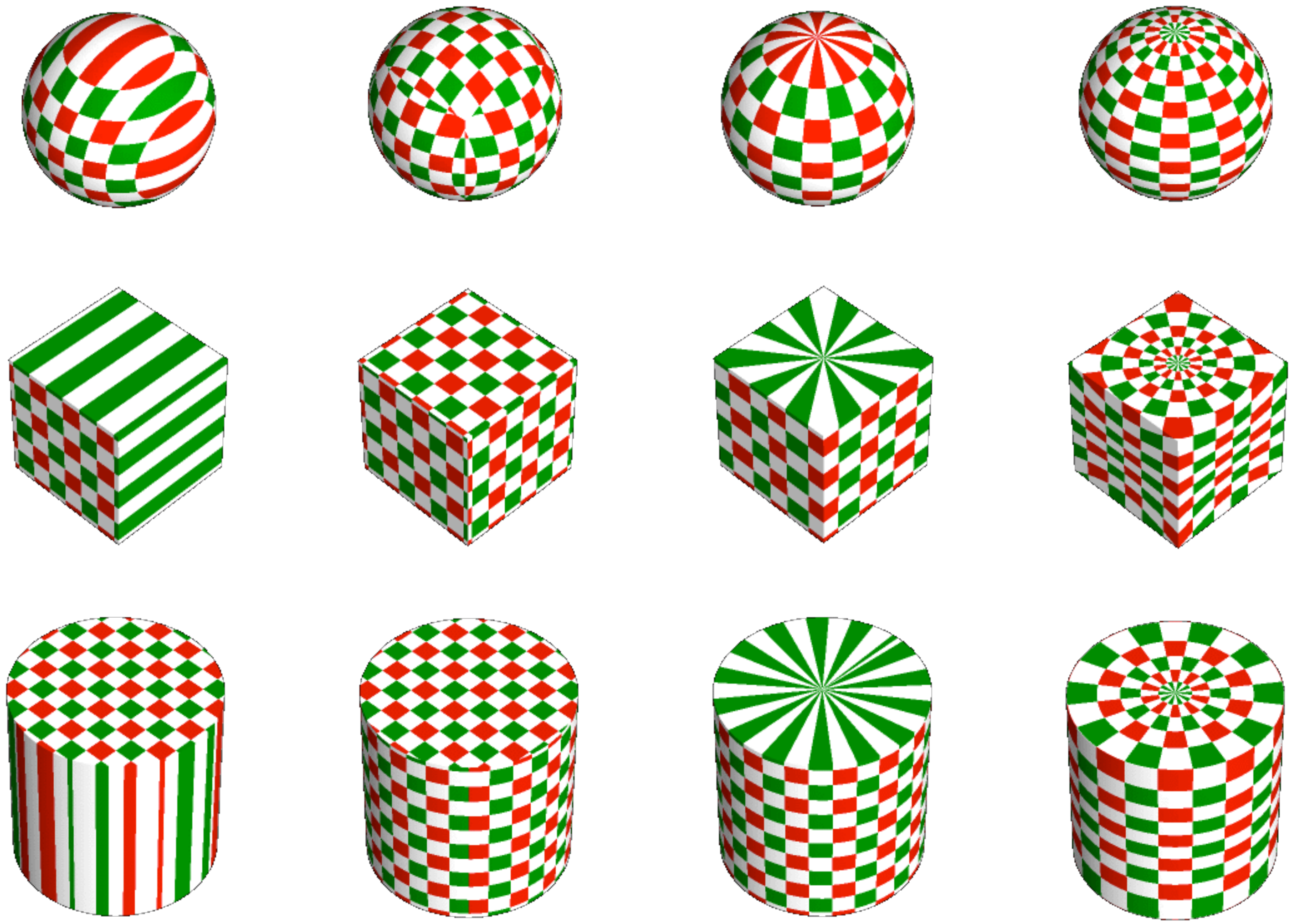
Texture Parameterization



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

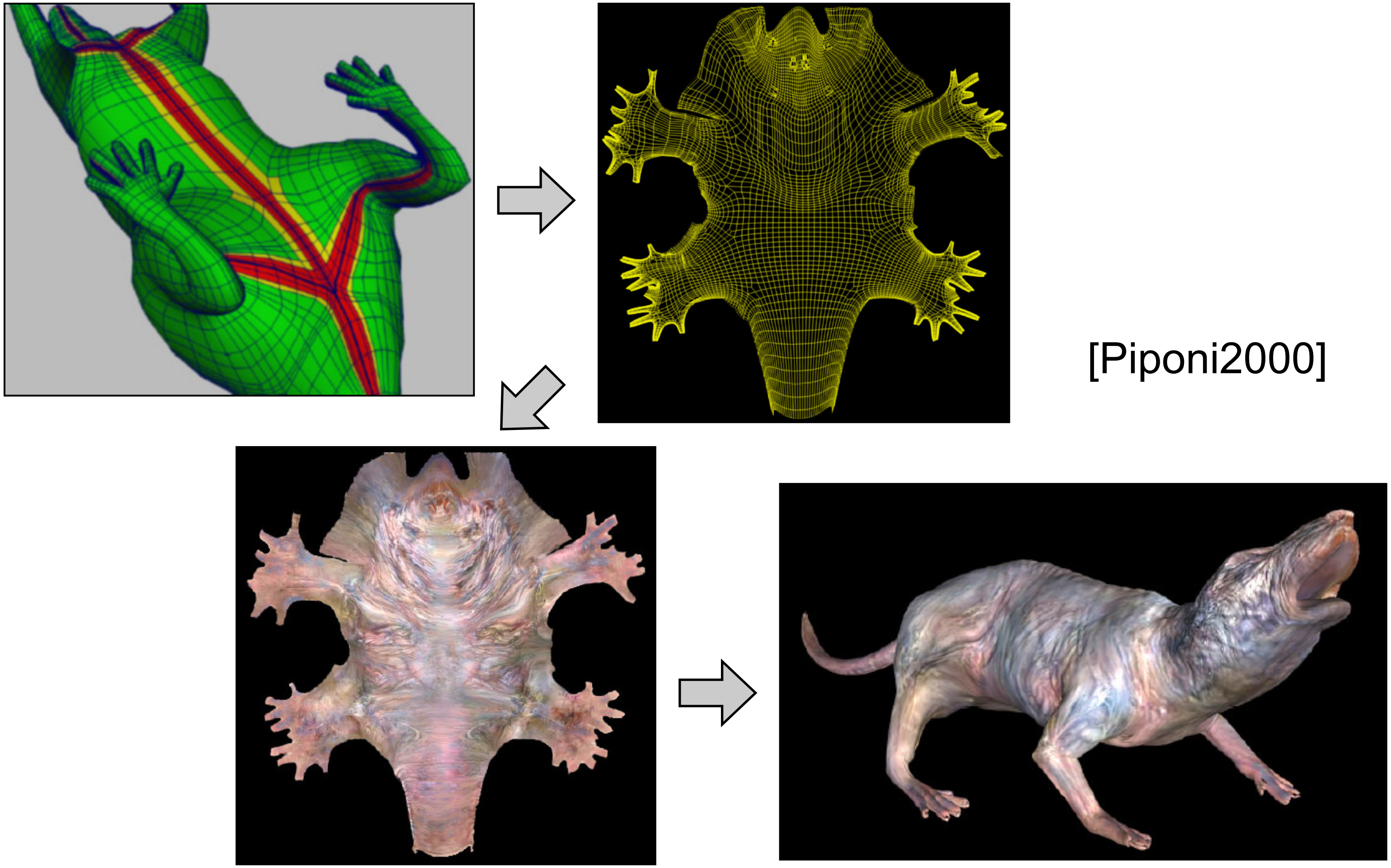
Texture Parameterization



[Paul Bourke]

Texture Parameterization

Option1: unfold the surface

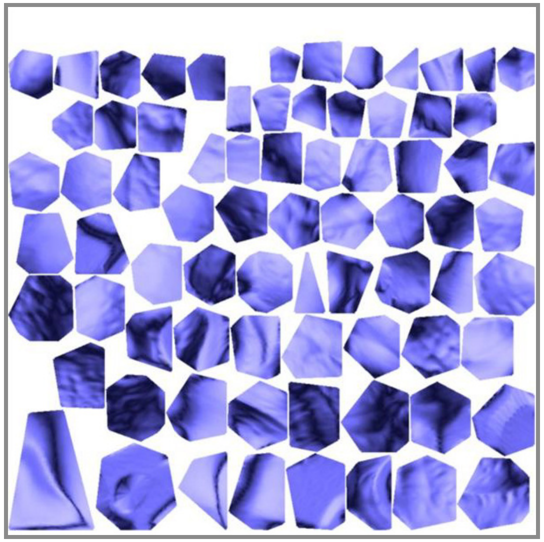


[Piponi2000]

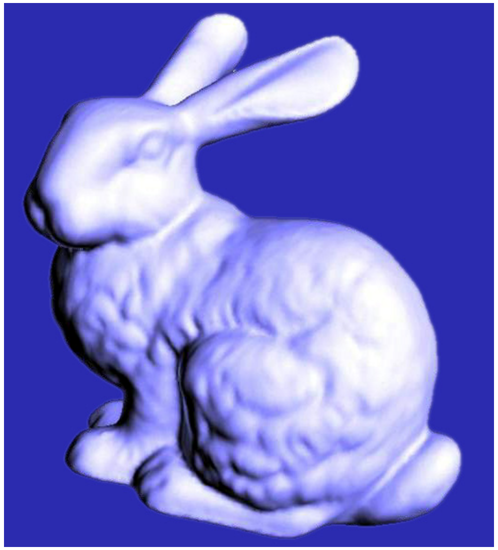
Texture Parameterization

Option2: make an atlas

charts



atlas



surface

[Sander2001]

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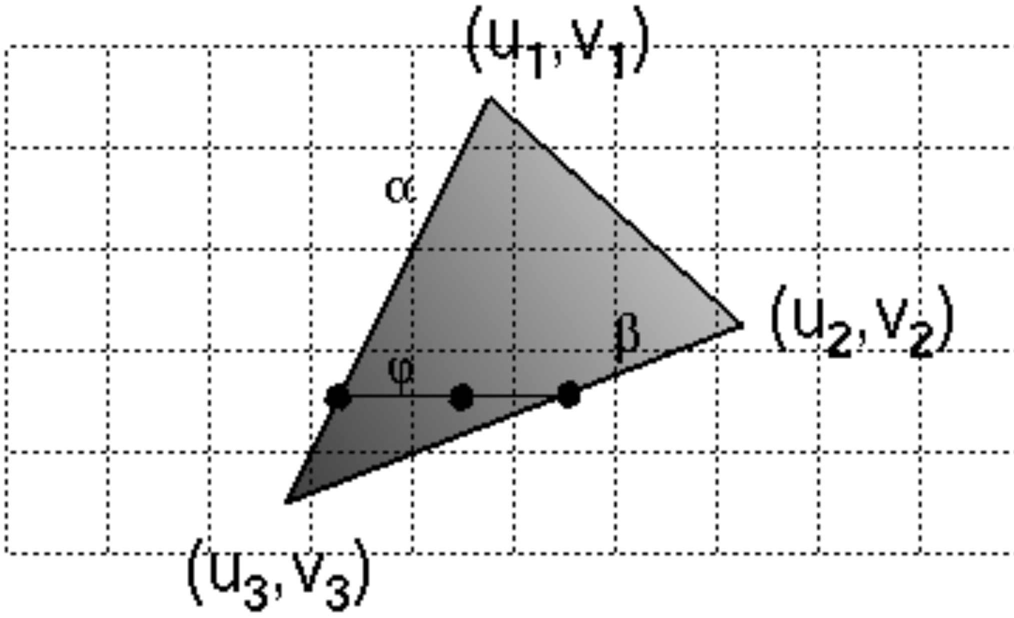
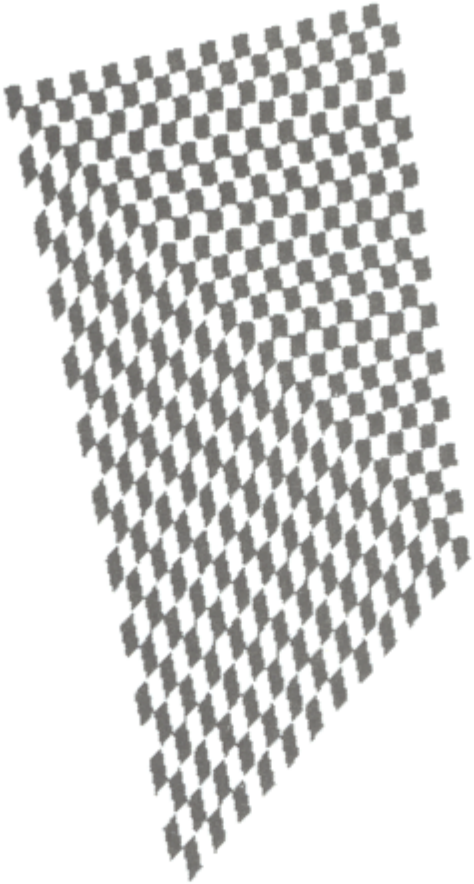
Texture Mapping

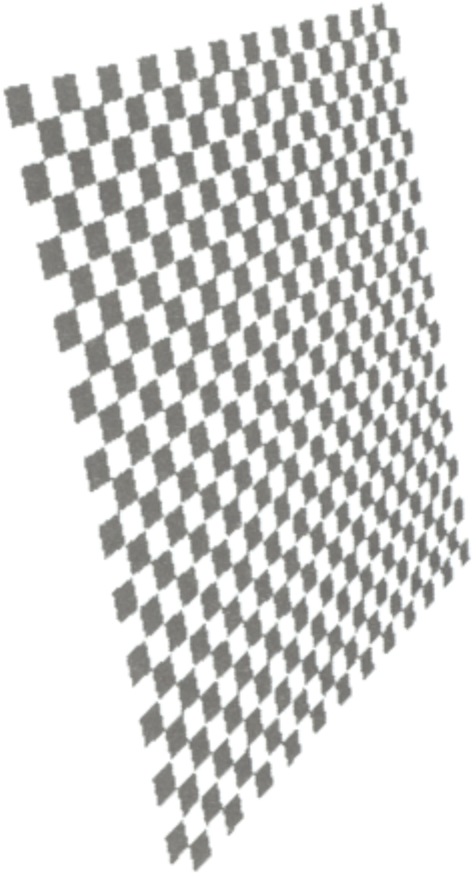
- Scan conversion
  - Interpolate texture coordinates down/across scan lines
  - Distortion due to bilinear interpolation approximation
    - » Cut polygons into smaller ones, or
    - » Perspective divide at each pixel



Texture Mapping



Linear interpolation of texture coordinates



Correct interpolation with perspective divide

Hill Figure 8.42

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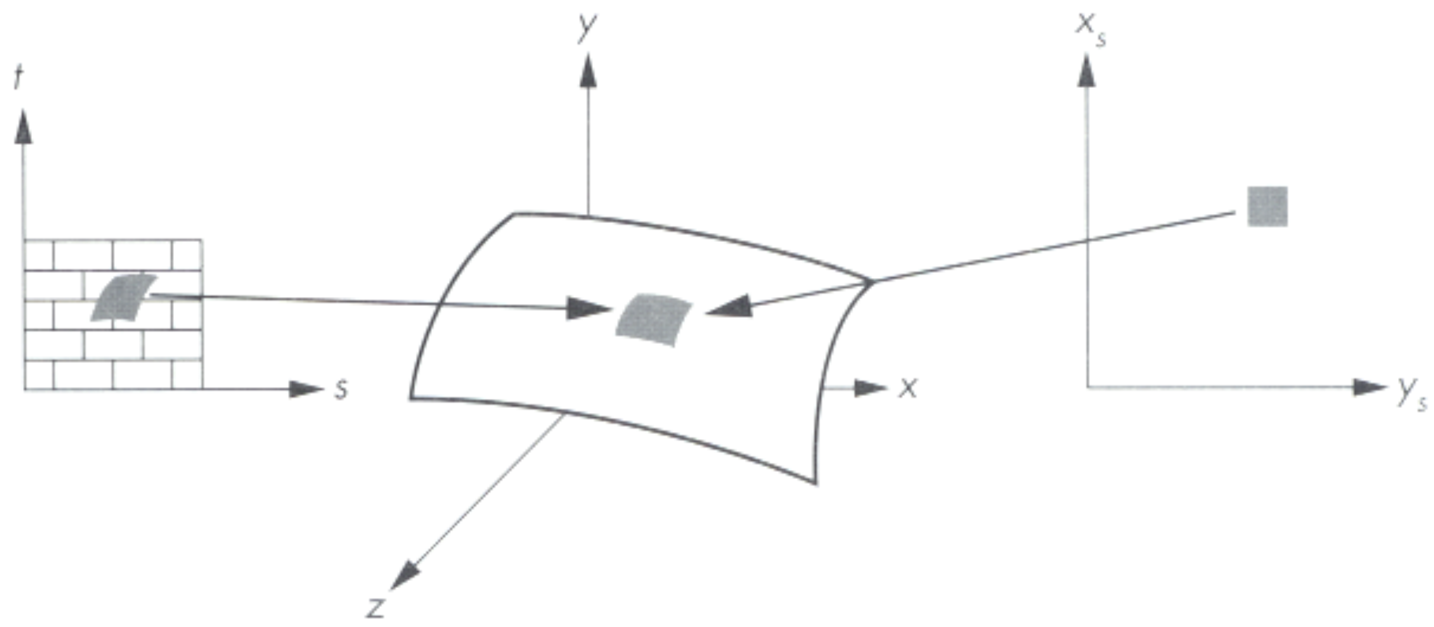
Texture Filtering

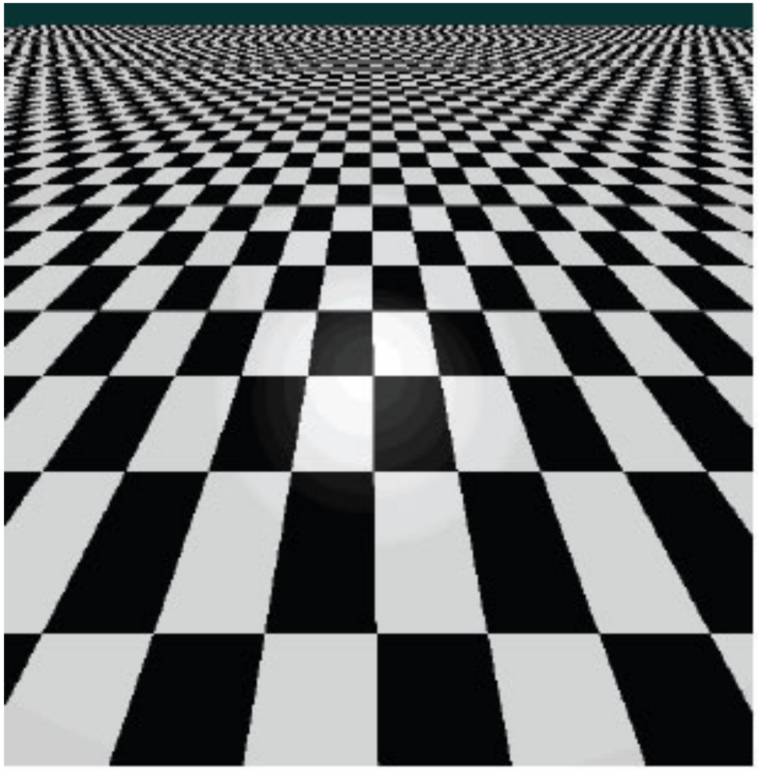
- Must sample texture to determine color at each pixel in image



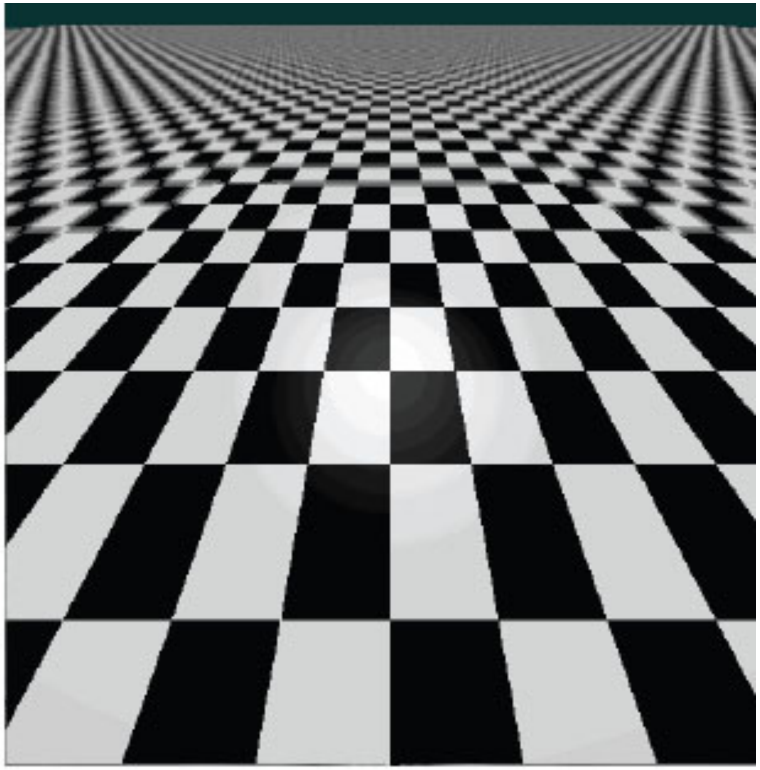
Angel Figure 9.4

Texture Filtering

- Aliasing is a problem



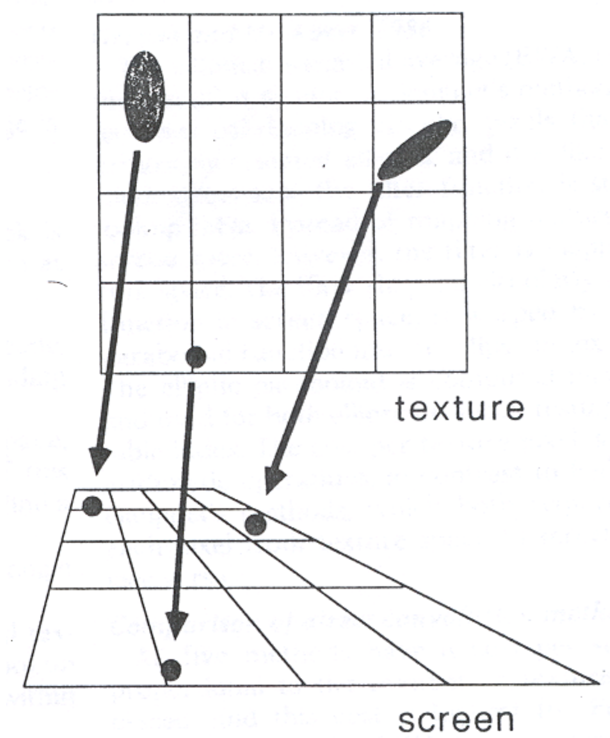
Point sampling



Area filtering

Texture Filtering

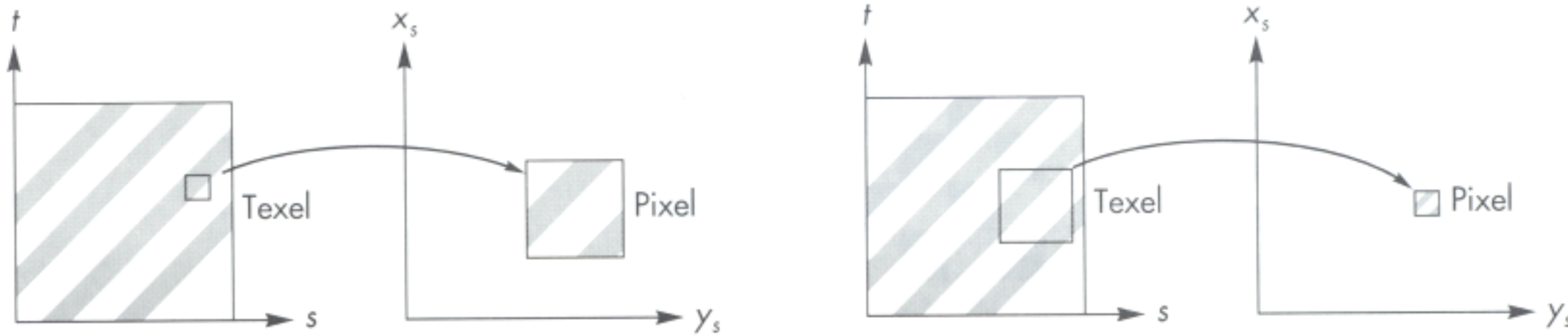
- Ideally, use elliptically shaped convolution filters



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

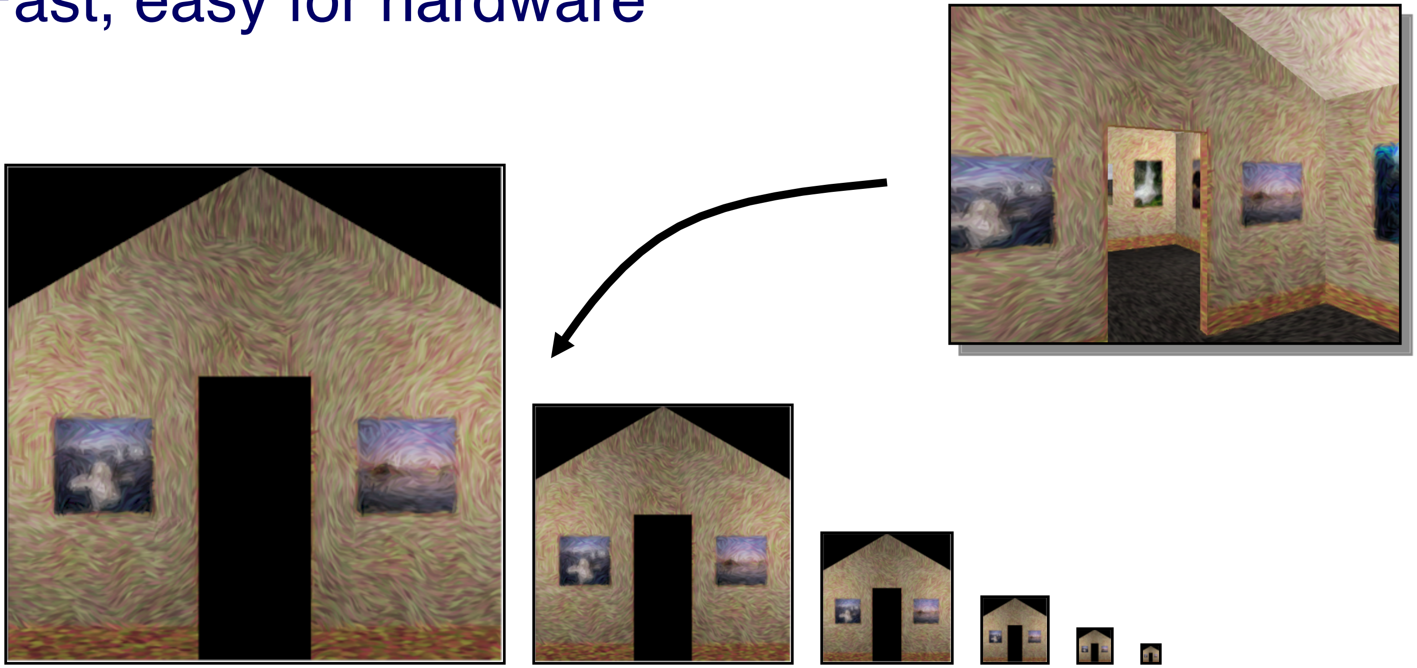


Magnification Minification

Angel Figure 9.14

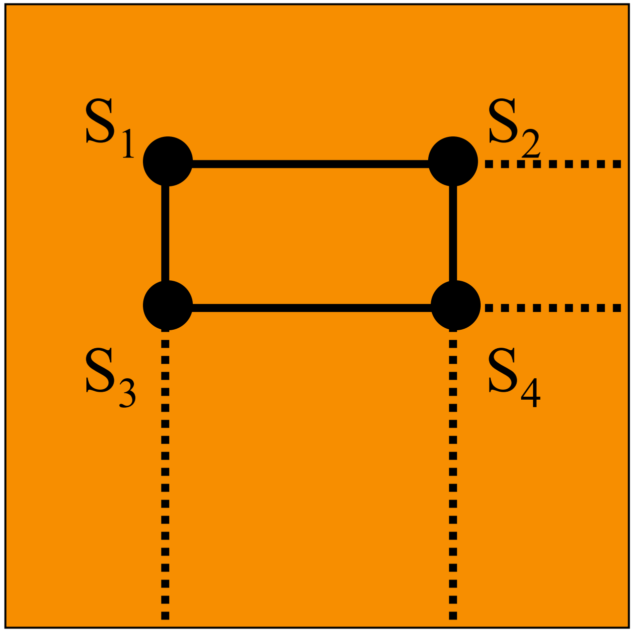
Mipmaps

- 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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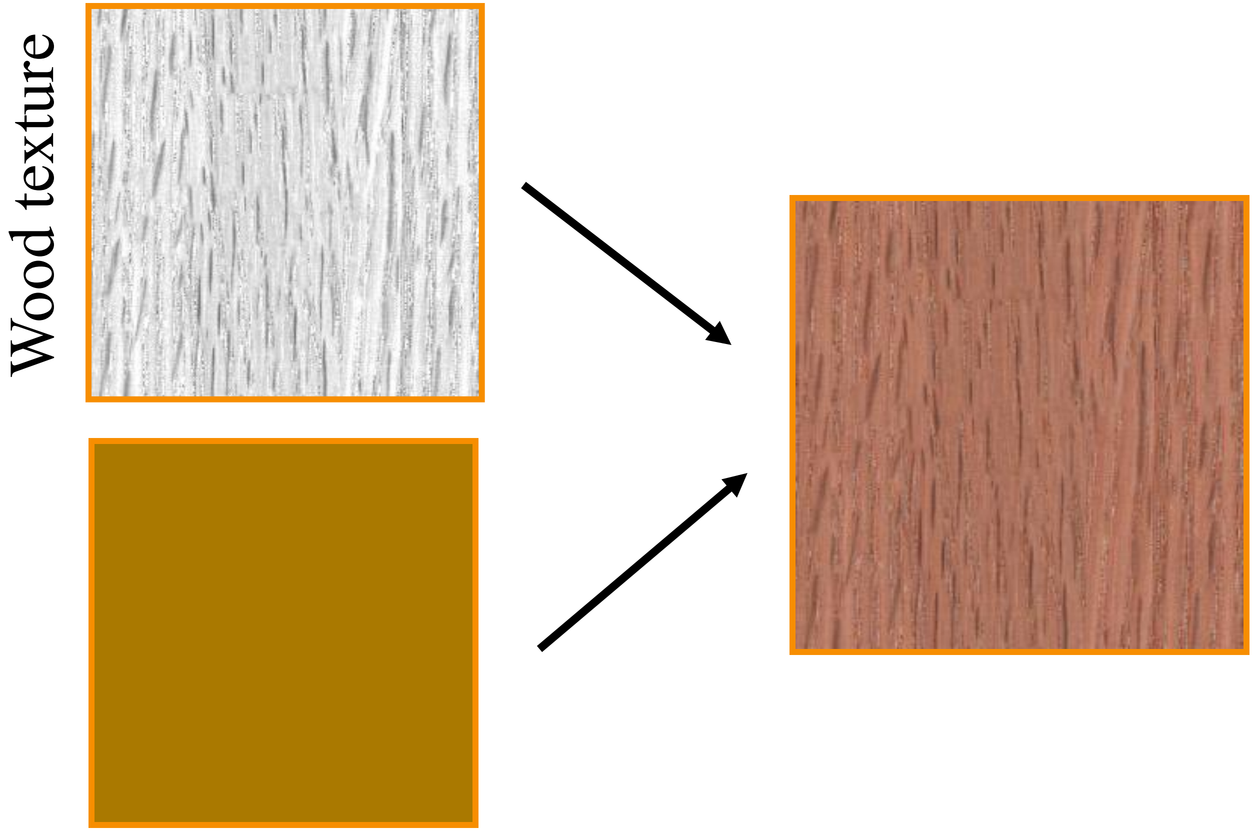
Modulation textures

Texture values scale result of lighting calculation



Texture value

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

Illumination Mapping

Map texture values to surface material parameter

- K_A
- K_D
- K_S
- K_T
- n

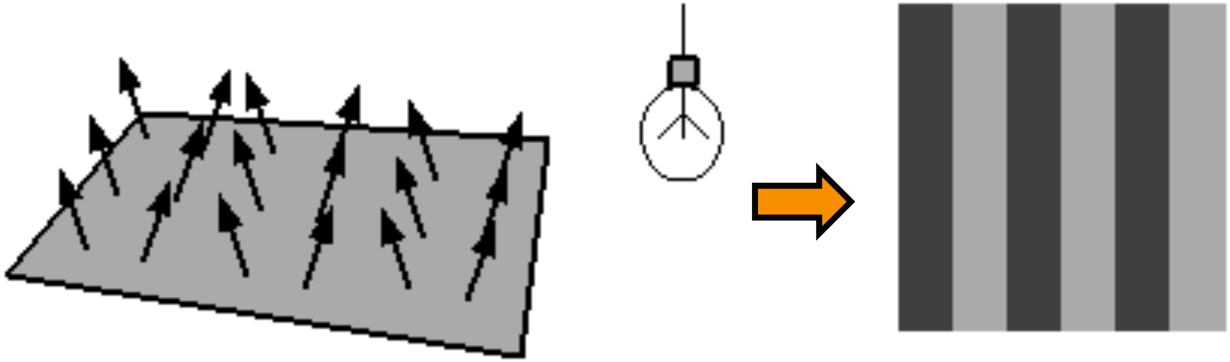
Texture value

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

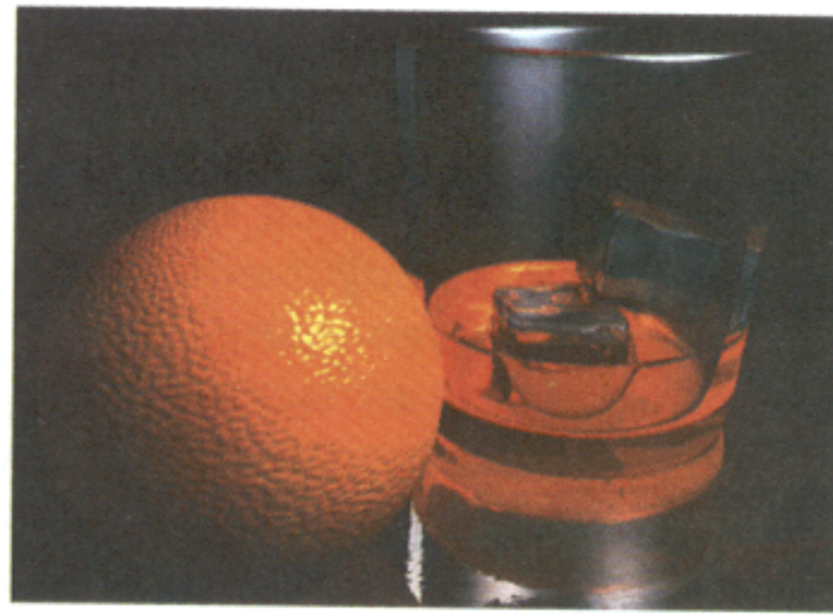
Bump/Normal Mapping

Texture values perturb surface normals:

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

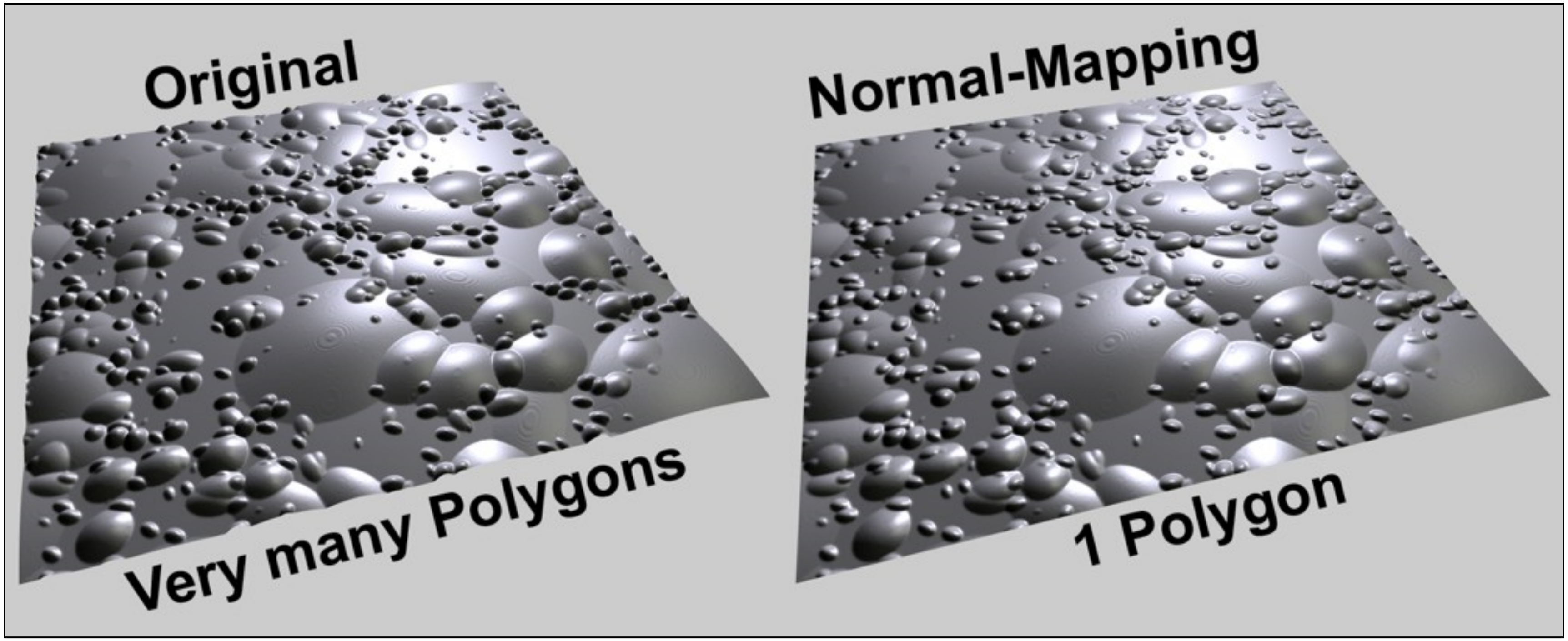


Bump Mapping



H&B Figure 14.100

Normal Mapping

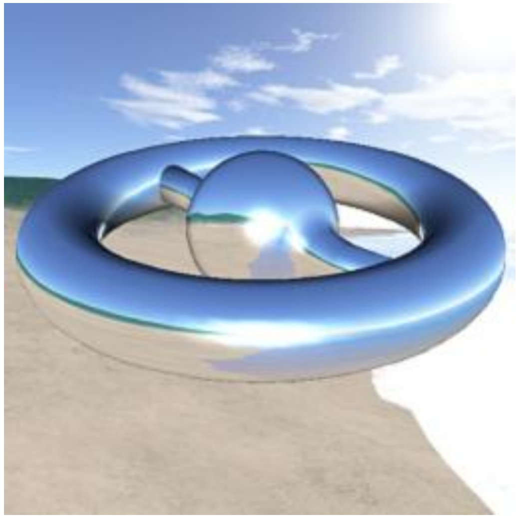


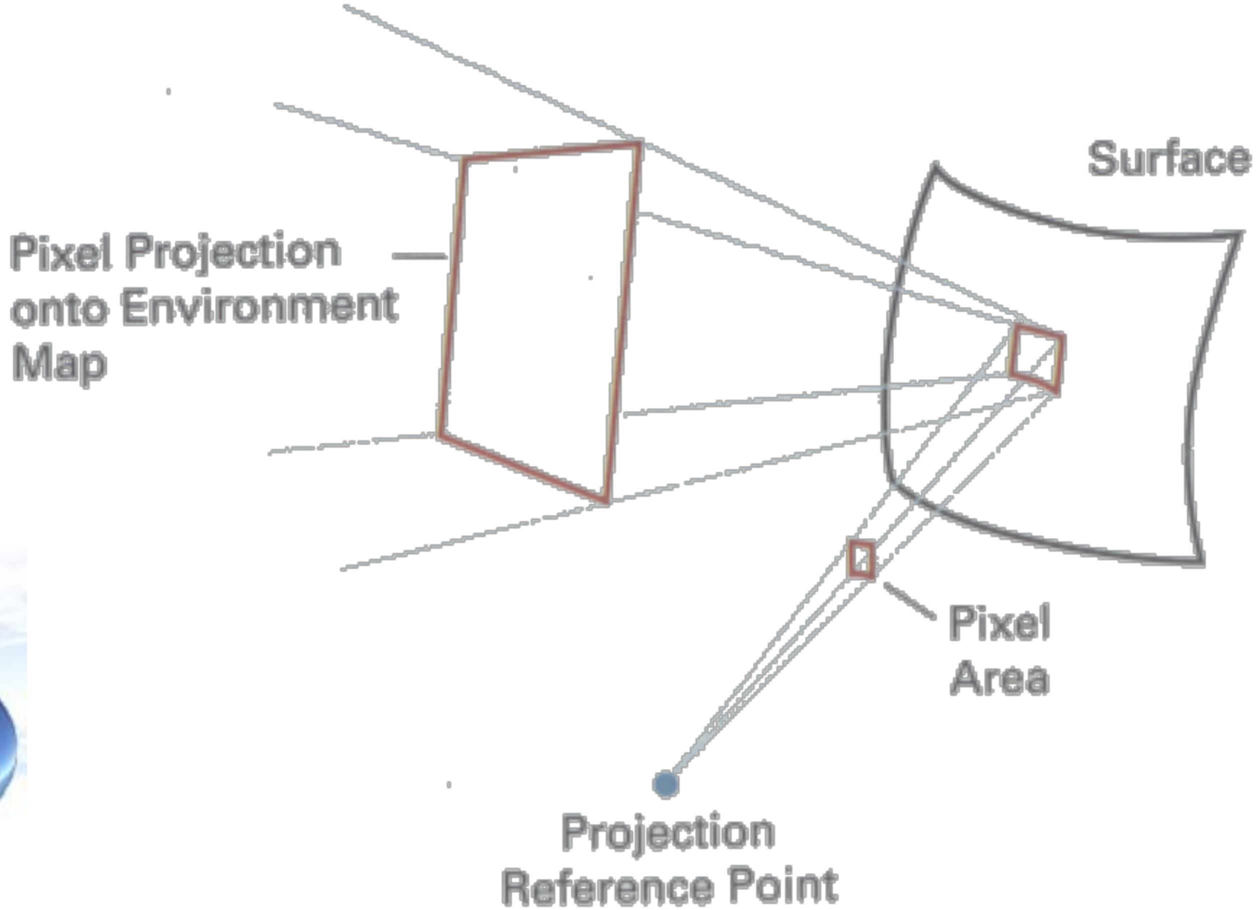
Graphisoft.com

Environment Mapping

Texture values are reflected off surface patch

Gamer3D/Wikipedia

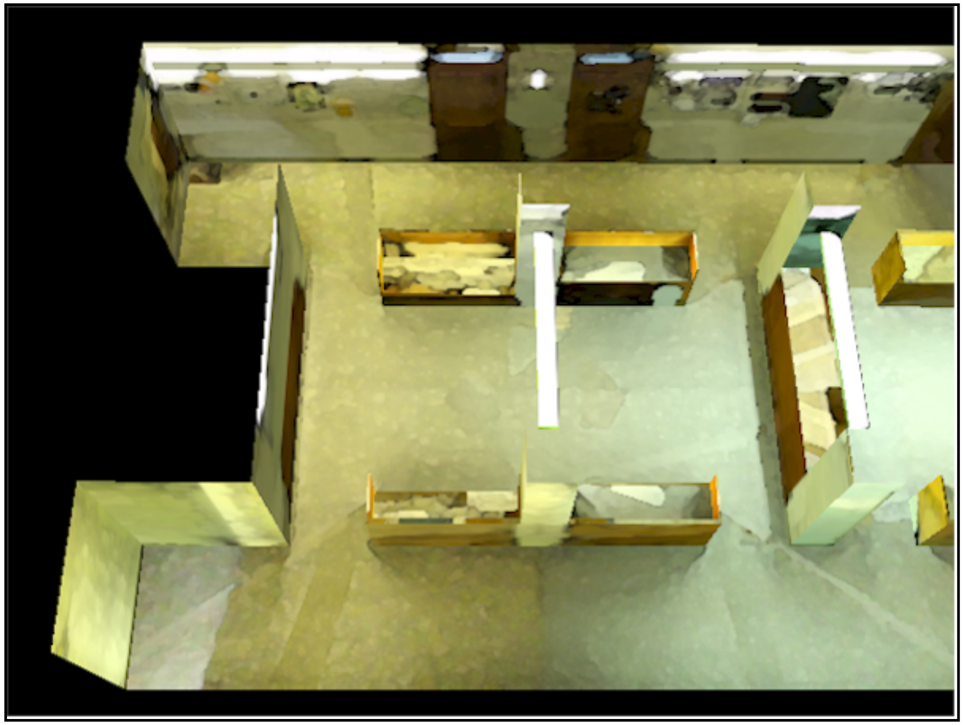




H&B Figure 14.93

Image-Based Rendering

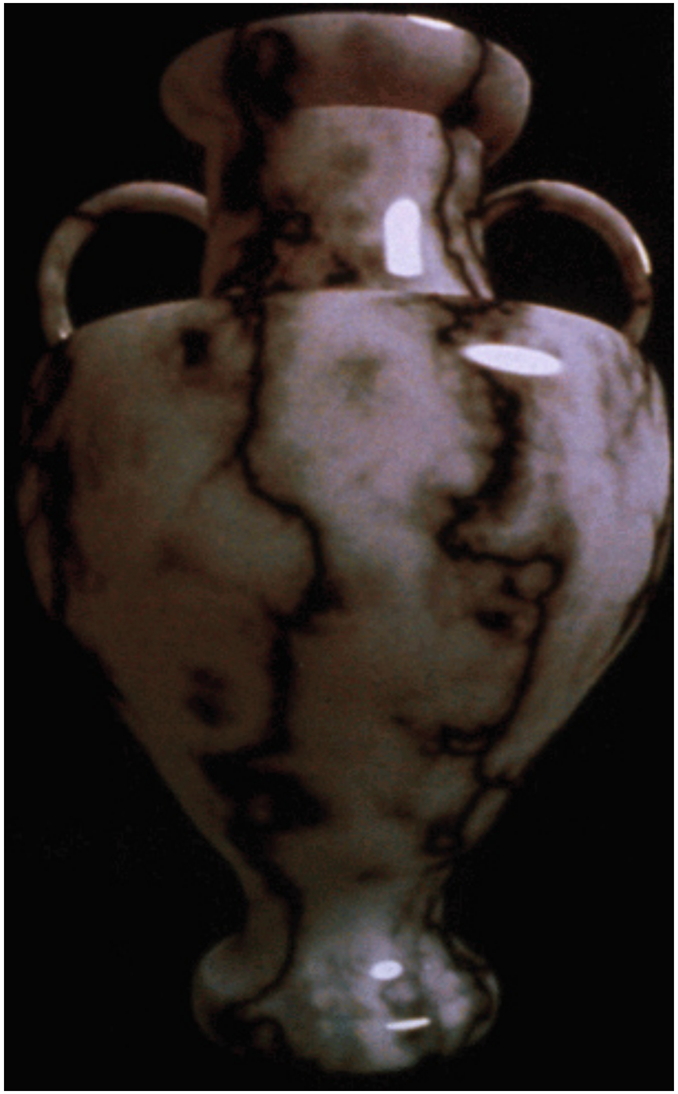
Map photographic textures to provide details for coarsely detailed polygonal model



Solid textures

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

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



Texture Summary

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  - Parameterization
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  - Modulation textures
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  - Environment mapping
  - Image-based rendering
  - Volume textures

Rasterization

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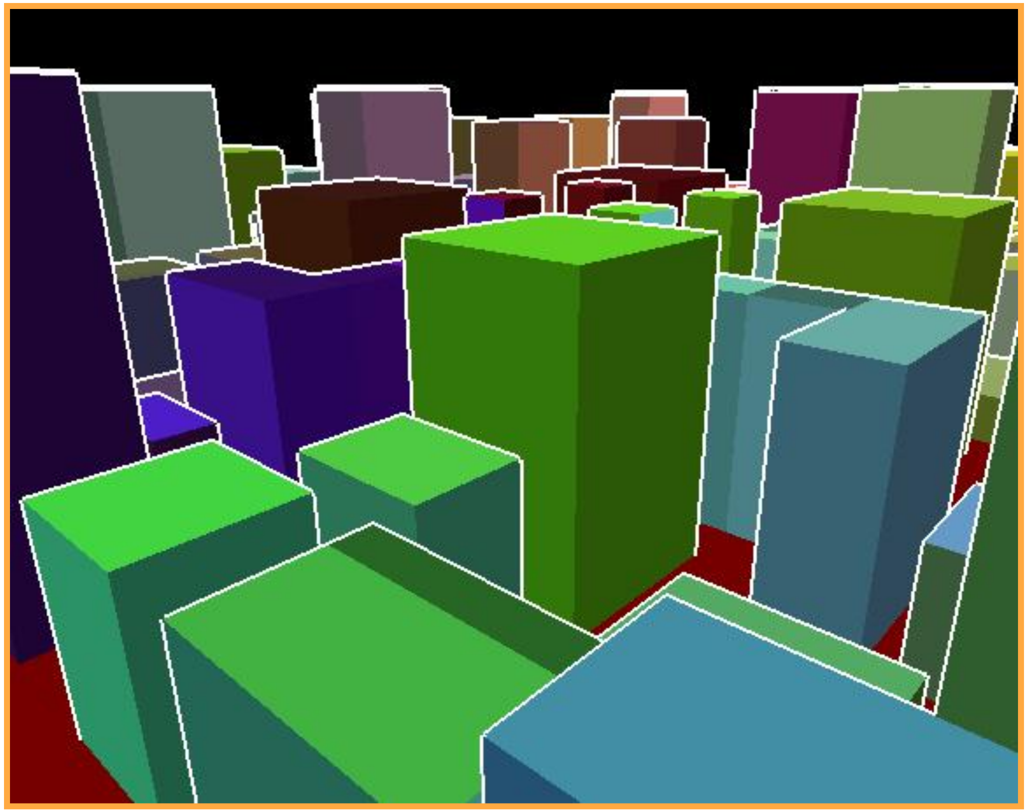
  - Describe shading variation within polygon interiors
- ➢ Visible surface determination
  - Figure out which surface is front-most at every pixel

Visible Surface Determination

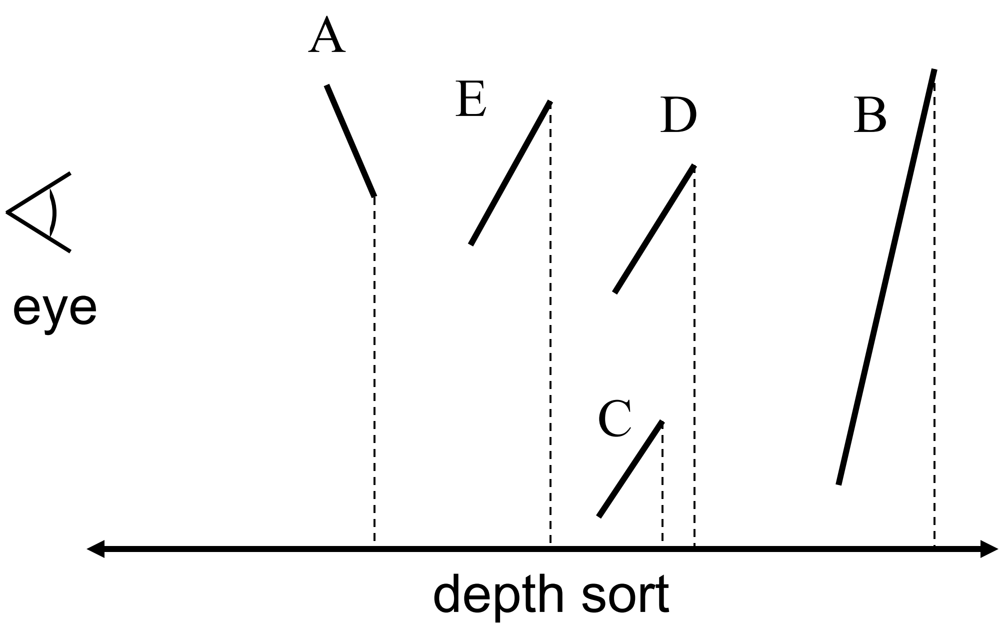
Make sure only front-most surface contributes to color at every pixel



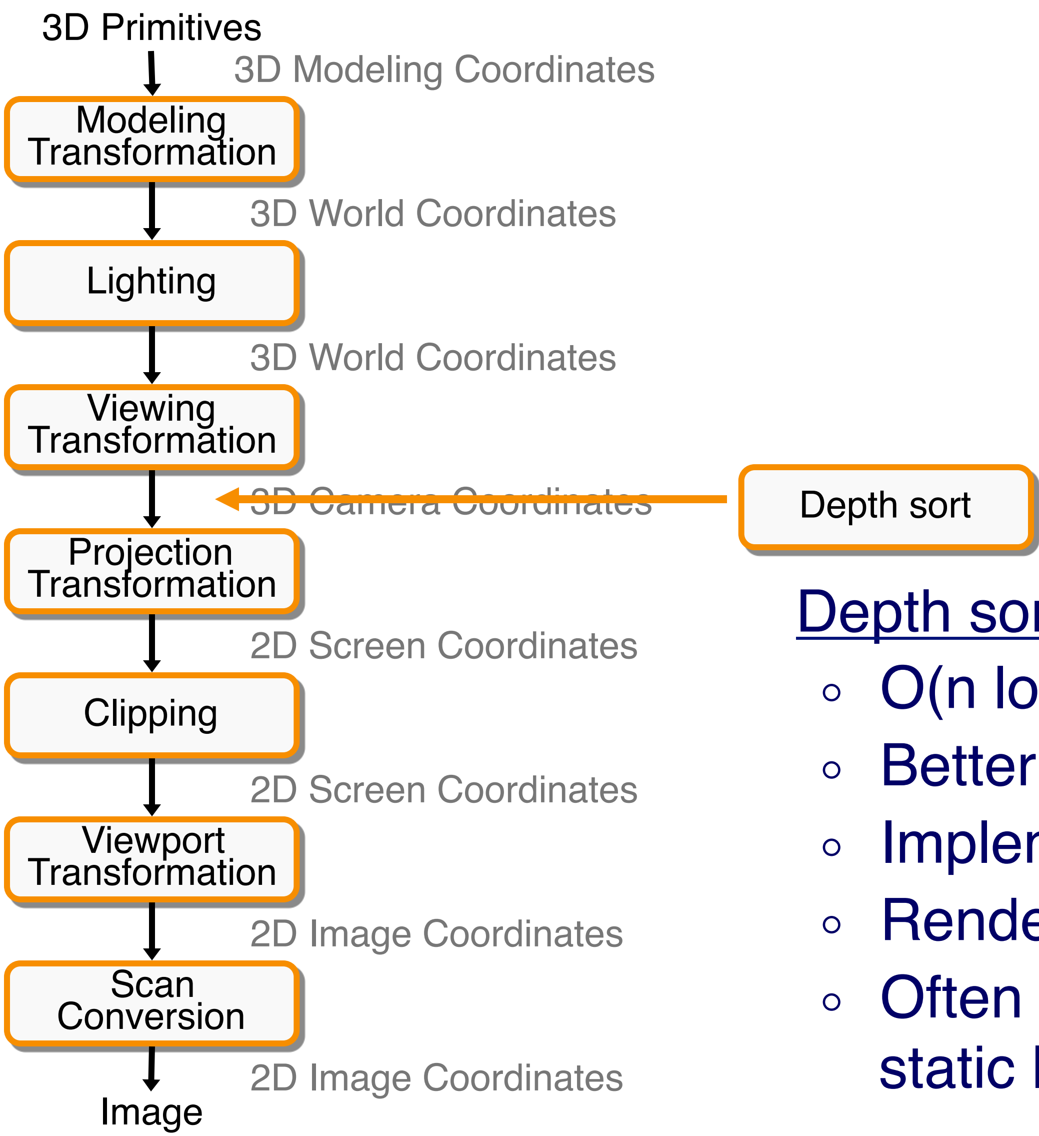
Depth sort

"Painter's algorithm"

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



3D Rendering Pipeline



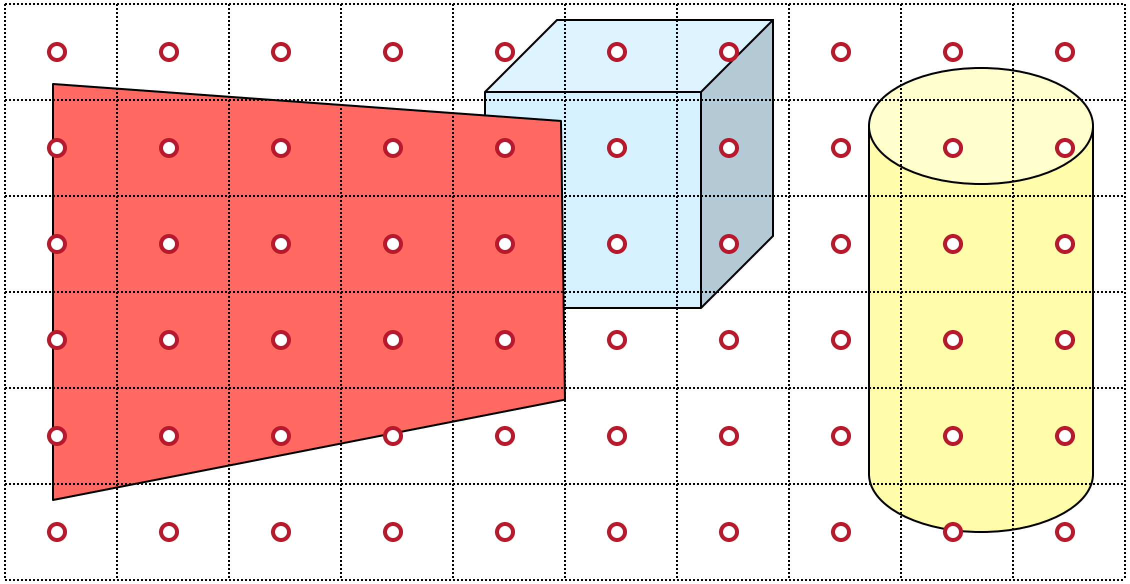
Depth sort comments

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

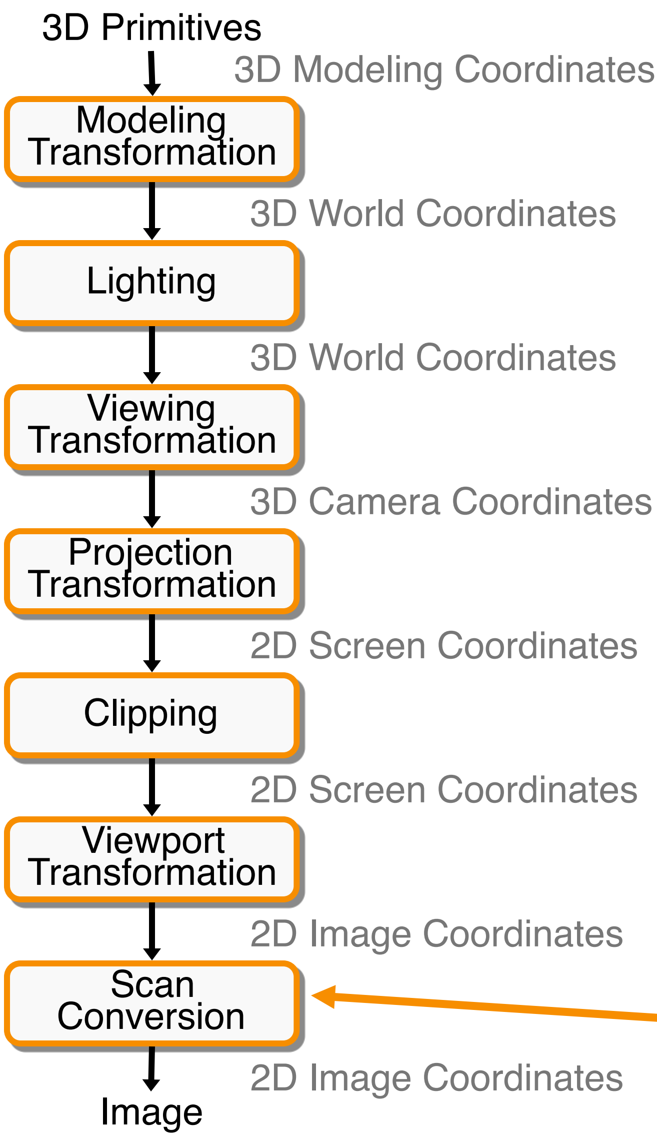
Z-Buffer

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

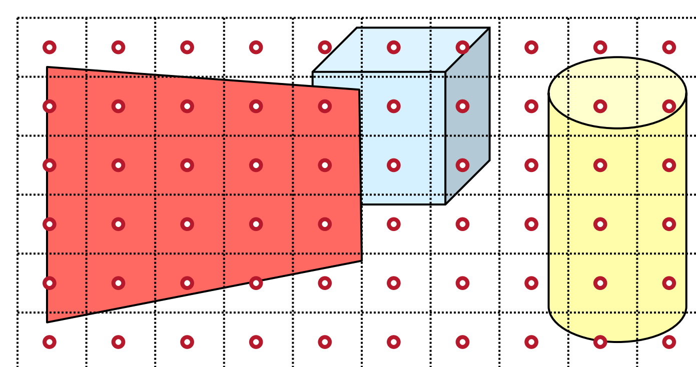


Z-Buffer



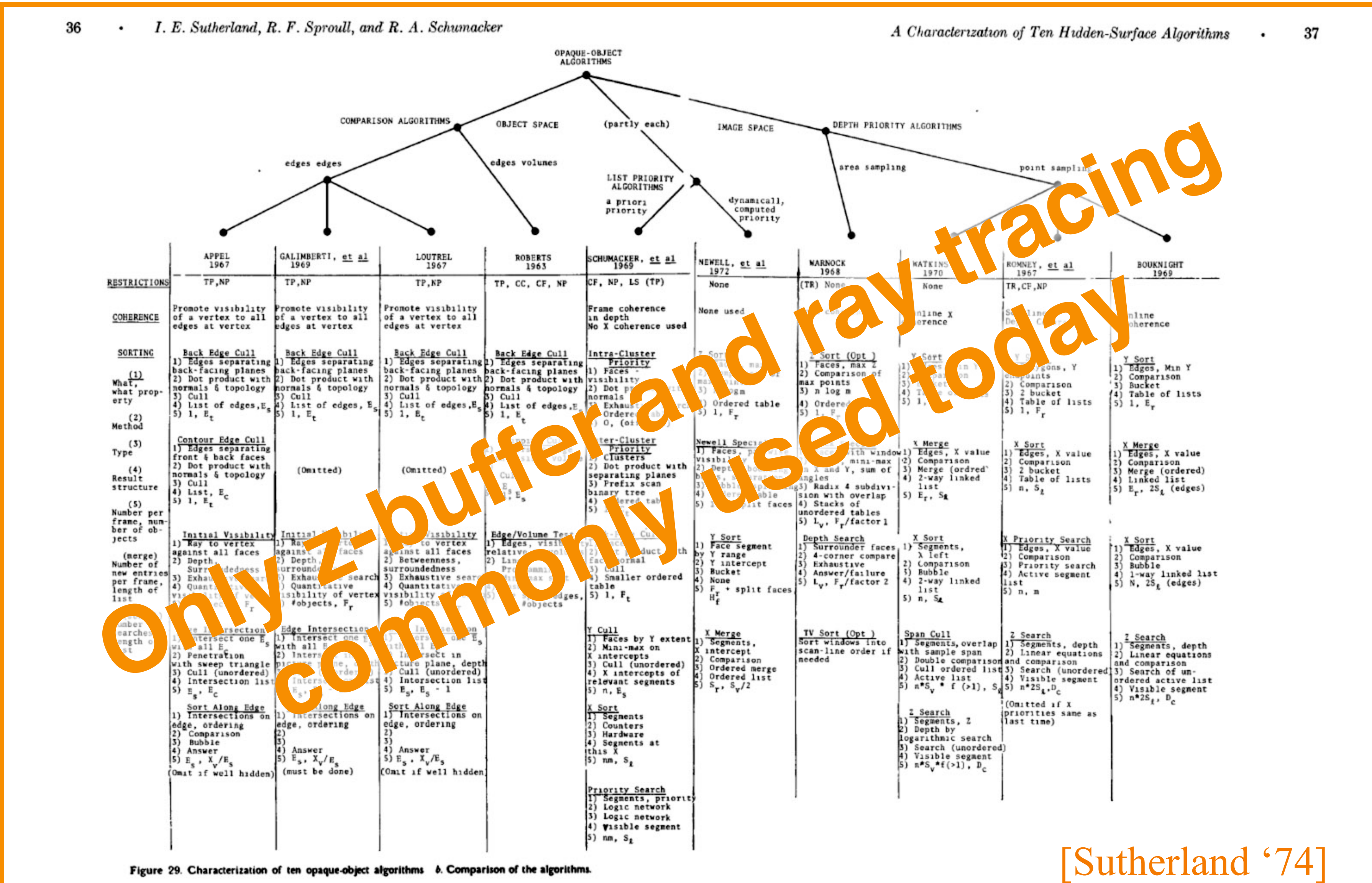
Z-buffer comments

+ 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

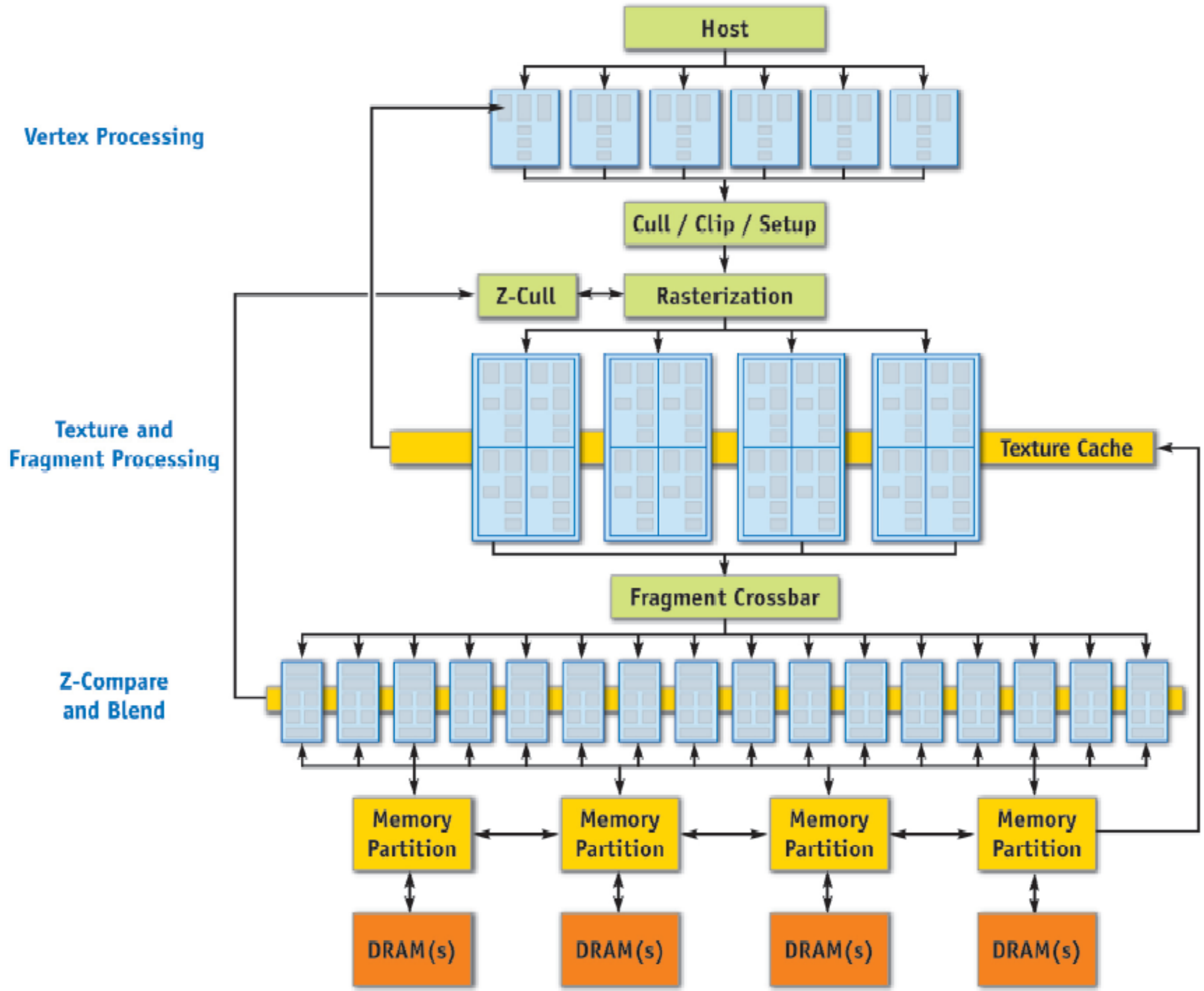
[Sutherland '74]

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

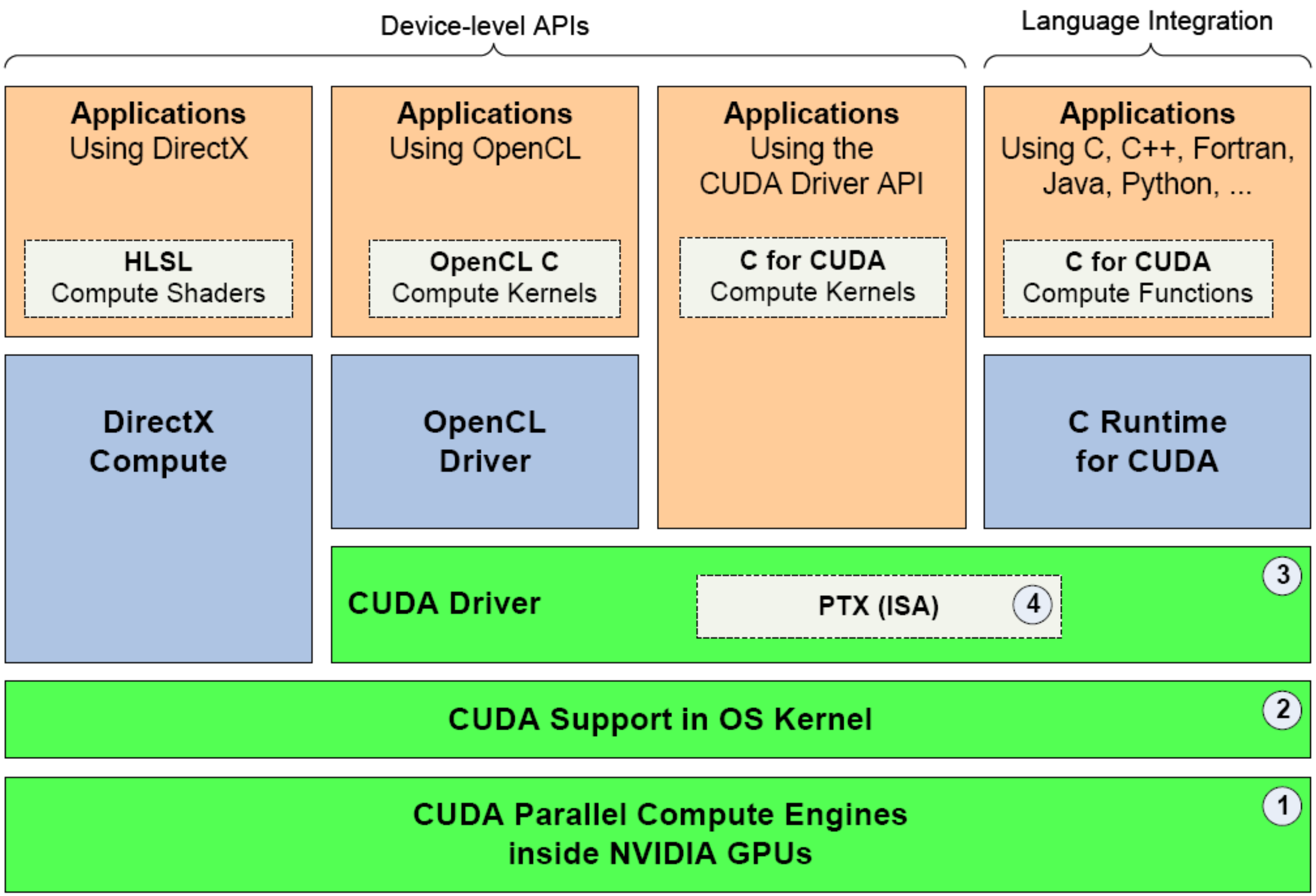


GeForce 6 Series Architecture

GPU Gems 2, NVIDIA

Actually …

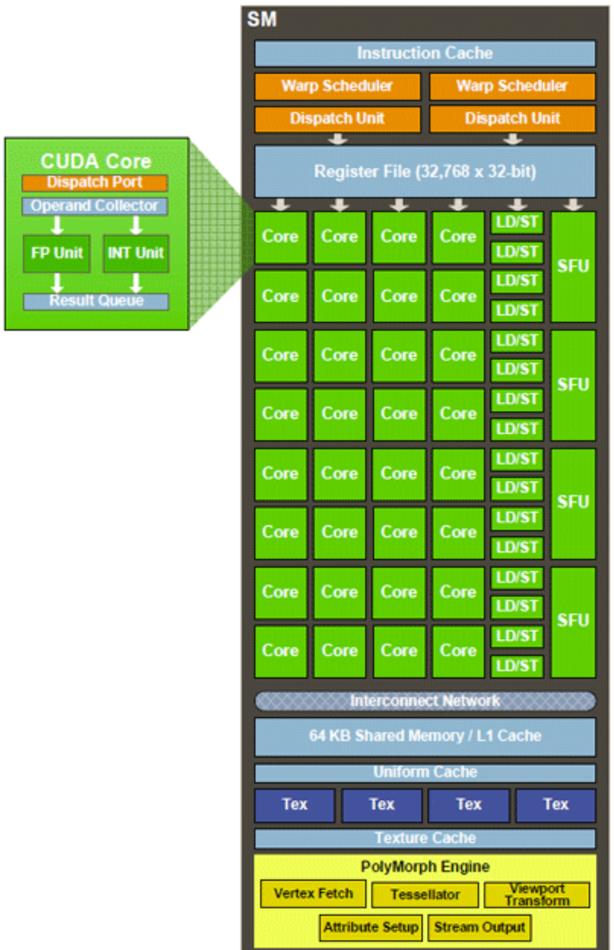
- Graphics hardware is programmable



www.nvidia.com/cuda

Trend …

- GPU is general-purpose parallel computer



www.nvidia.com/cuda