Texture Mapping & Hidden Surface Removal

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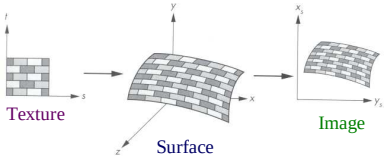
COS 426, Spring 2004

Textures

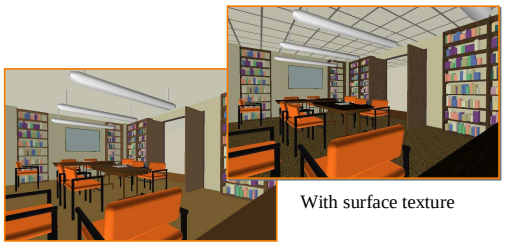
- Describe color variation in interior of 3D polygon
  - When scan converting a polygon, vary pixel colors according to values fetched from a texture



Angel Figure 9.3

Surface Textures

- Add visual detail to surfaces of 3D objects



With surface texture

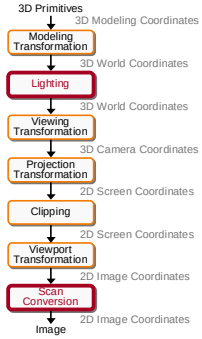
Polygonal model

Surface Textures

- Add visual detail to surfaces of 3D objects

[Daren Horley]

3D Rendering Pipeline (for direct illumination)

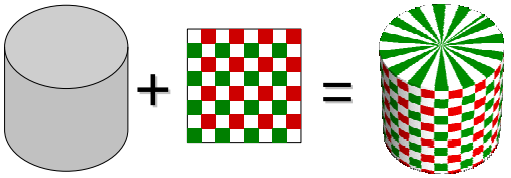


Texture mapping

Texture Mapping Overview

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

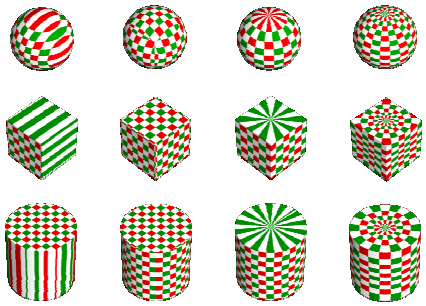
Parameterization



geometry image texture map

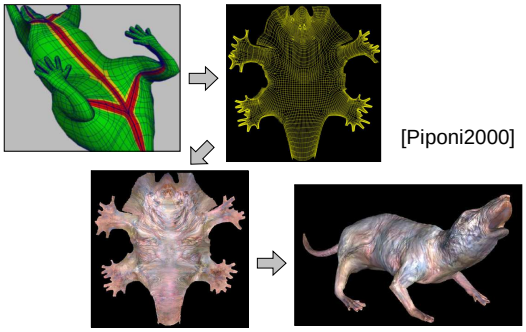
- Q: How do we decide *where* on the geometry each color from the image should go?

Option: Varieties of projections



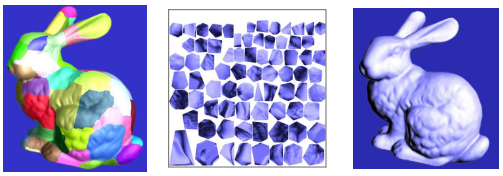
[Paul Bourke]

Option: unfold the surface



[Piponi2000]

Option: make an atlas



charts atlas surface

[Sander2001]

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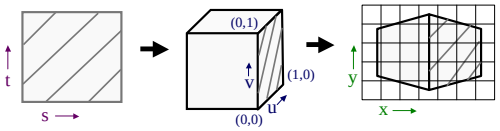
Texture Mapping

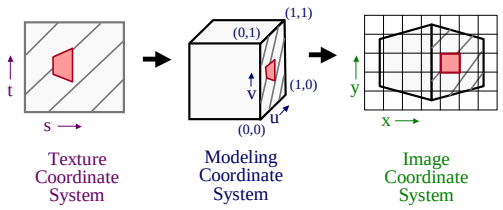
- Steps:
  - Define texture
  - Specify mapping from texture to surface
  - Lookup texture values during scan conversion



Texture Coordinate System | Modeling Coordinate System | Image Coordinate System

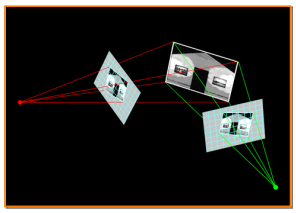
Texture Mapping

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



Texture Mapping

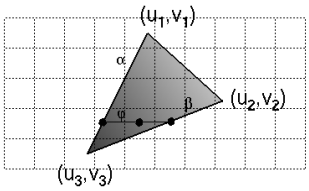
- Texture mapping is a 2D projective transformation
  - texture coordinate system: (t,s) to
  - image coordinate system (x,y)



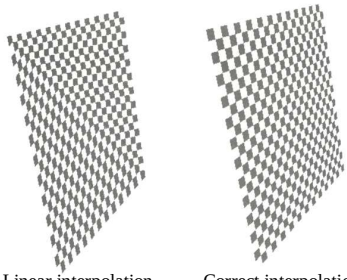
Allison Klein, Princeton

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

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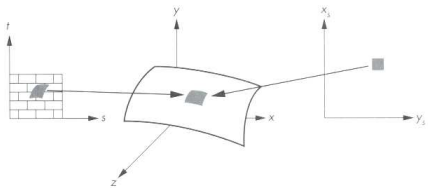
Texture Filtering

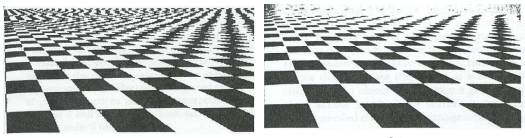
- Must sample texture to determine color at each pixel in image



Angel Figure 9.4

Texture Filtering

- Aliasing is a problem

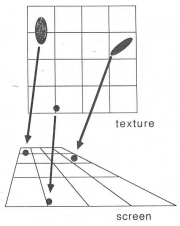


Point sampling | Area filtering

Angel Figure 9.5

Texture Filtering

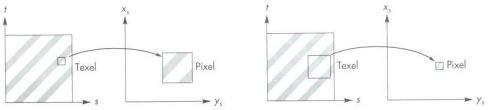
- Ideally, use elliptically shaped convolution filters



In practice, use rectangles

Texture Filtering

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

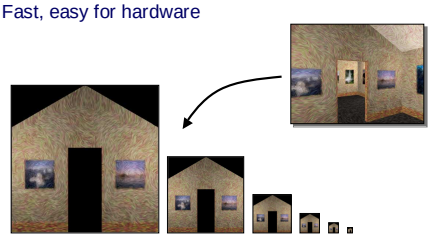


Magnification | Minification

Angel Figure 9.14

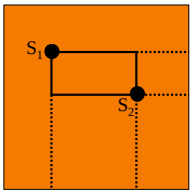
Mip Maps

- 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



Overview

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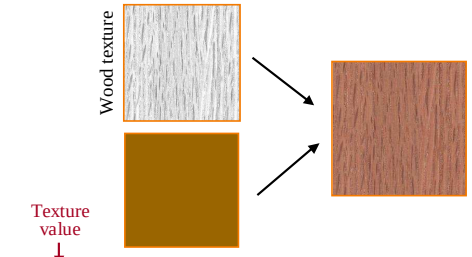
Modulation textures

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

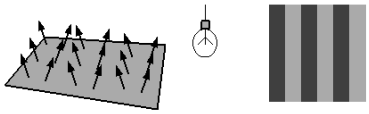
- K_A
- K_D
- K_S
- K_T
- n

$K_T = T(s,t)$

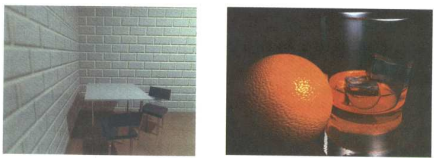
$$I = I_E + K_A I_A + \sum_L (K_D (N \bullet L) + K_S (V \bullet R)^n) S_L I_L + K_T I_T + K_S I_S$$

Bump Mapping

Texture values perturb surface normals



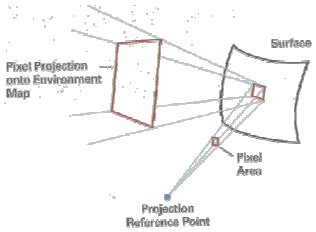
Bump Mapping



H&B Figure 14.100

Environment Mapping

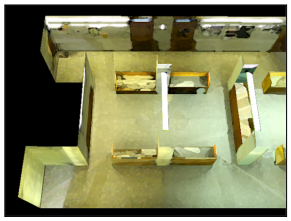
Texture values are reflected off surface patch



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 à

Texture Mapping Summary

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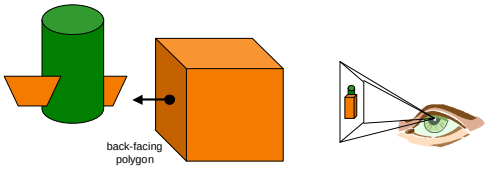
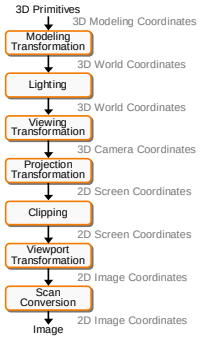
  - Environment mapping
  - Image-based rendering
  - Volume textures

Hidden Surface Removal (HSR)

- Surfaces may be back-facing.
- Surfaces may be occluded.
- Surfaces may overlap in the image plane.
- Surfaces may intersect.

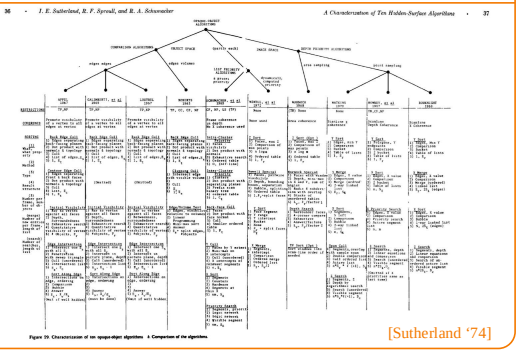


3D Rendering Pipeline



Somewhere in here we have to decide which objects are visible, and which objects are hidden.

HSR Algorithms

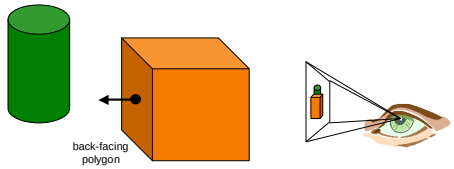


[Sutherland '74]

Hidden Surface Removal Algorithms

- Object space
  - Back-face detection
  - Depth sort
- Screen space
  - Ray casting
  - Scan-line
  - Z-buffer
  - Area subdivision

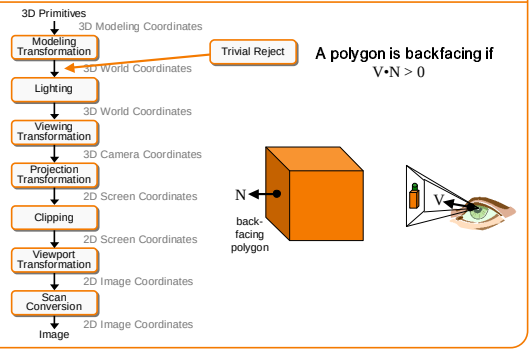
Back-face detection



Q: How do we test for back-facing polygons?

A: Dot product of the normal and view directions.

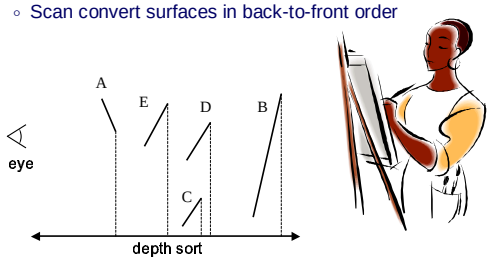
3D Rendering Pipeline



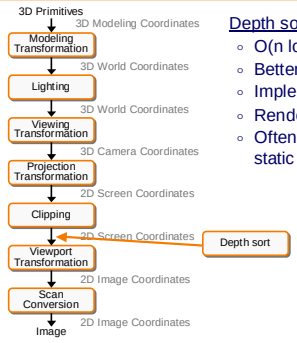
Depth sort

"Painter's algorithm"

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



3D Rendering Pipeline

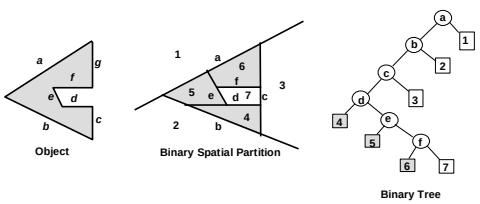


Depth sort comments

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

BSP Tree

- Binary space partition with solid cells labeled
  - Constructed from polygonal representations
  - Provides linear-time depth sort for arbitrary view



(We'll come back to this…)

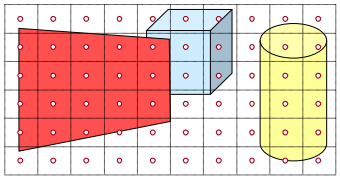
Naylor

Hidden Surface Removal Algorithms

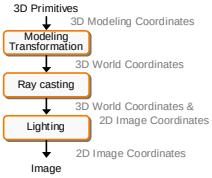
- Object space
  - Back-face detection
  - Depth sort
- Screen space
  - Ray casting
  - Scan-line
  - Z-buffer
  - Area subdivision

Ray Casting

- Fire a ray for every pixel
  - If ray intersects multiple objects, take the closest



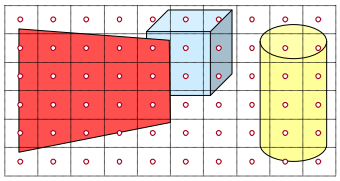
Ray Casting Pipeline



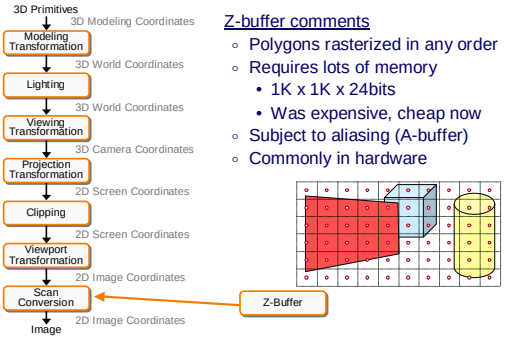
Ray casting comments
- O(p log n) for p pixels
- May (or not) use pixel coherence
- Simple, but generally not used

Z-Buffer

- Color & depth of closest object for every pixel
  - Update only pixels whose depth is closer than in buffer
  - Depths are interpolated from vertices, just like colors



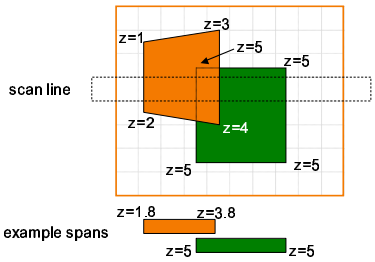
3D Rendering Pipeline



Z-buffer comments
- Polygons rasterized in any order
- Requires lots of memory
  - 1K x 1K x 24bits
  - Was expensive, cheap now
- Subject to aliasing (A-buffer)
- Commonly in hardware

Scan-Line Algorithm

- For each scan line, construct spans
  - Sort by depth



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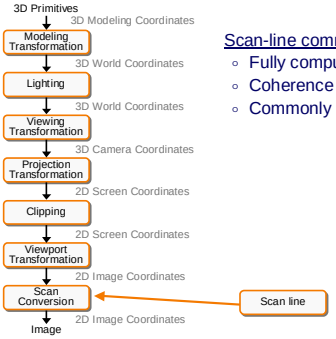
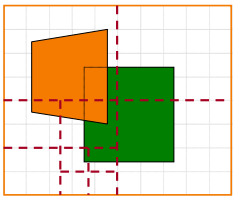


Scan-line comments
- Fully compute only visible pixels
- Coherence among along scans
- Commonly in software

Area Subdivision

Warnock's algorithm

- Fill area if:
  - » All surfaces are outside area, or
  - » Only one surface intersects area, or
  - » One surface occludes other surfaces in area
- Otherwise, subdivide



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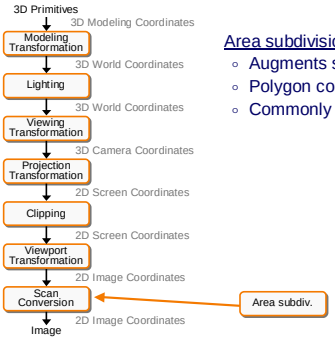

Area subdivision comments

- Augments scan conversion
- Polygon coherence
- Commonly in software

Summary

- Texture Mapping
  - Add detail during scan conversion
- Hidden surface removal
  - Find visible surfaces