Pipeline Operations

CS 4620 Lecture 14
Pipeline

you are here

APPLICATION

COMMAND STREAM

VERTEX PROCESSING

TRANSFORMED GEOMETRY

RASTERIZATION

FRAGMENTS

FRAGMENT PROCESSING

FRAMEBUFFER IMAGE

DISPLAY

3D transformations; shading

conversion of primitives to pixels

blending, compositing, shading

user sees this
Pipeline of transformations

- Standard sequence of transforms
Hidden surface elimination

• We have discussed how to map primitives to image space
  – projection and perspective are depth cues
  – occlusion is another very important cue
Back face culling

- For closed shapes you will never see the inside
  - therefore only draw surfaces that face the camera
  - implement by checking $\mathbf{n} \cdot \mathbf{v}$
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Painter’s algorithm

- Simplest way to do hidden surfaces
- Draw from back to front, use overwriting in framebuffer
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• Amounts to a topological sort of the graph of occlusions
  – that is, an edge from A to B means A sometimes occludes B
  – any sort is valid
    • ABCDEF
    • BADCFE
  – if there are cycles there is no sort
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[Foley et al.]
Painter’s algorithm

- Useful when a valid order is easy to come by
- Compatible with alpha blending
The z buffer

• In many (most) applications maintaining a z sort is too expensive
  – changes all the time as the view changes
  – many data structures exist, but complex
• Solution: draw in any order, keep track of closest
  – allocate extra channel per pixel to keep track of closest depth so far
  – when drawing, compare object’s depth to current closest depth and discard if greater
  – this works just like any other compositing operation
The $z$ buffer

- another example of a memory-intensive brute force approach that works and has become the standard
Precision in z buffer

• The precision is distributed between the near and far clipping planes
  – this is why these planes have to exist
  – also why you can’t always just set them to very small and very large distances
• Generally use z’ (not world z) in z buffer
Interpolating in projection

linear interp. in screen space ≠ linear interp. in world (eye) space
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Pipeline for minimal operation

- **Vertex stage** (input: position / vtx; color / tri)
  - transform position (object to screen space)
  - pass through color

- **Rasterizer**
  - pass through color

- **Fragment stage** (output: color)
  - write to color planes
Result of minimal pipeline
Pipeline for basic z buffer

- **Vertex stage** (input: position / vtx; color / tri)
  - transform position (object to screen space)
  - pass through color

- **Rasterizer**
  - interpolated parameter: $z'$ (screen z)
  - pass through color

- **Fragment stage** (output: color, $z'$)
  - write to color planes only if interpolated $z' < \text{current } z'$
Result of z-buffer pipeline
Flat shading

• Shade using the real normal of the triangle
  – same result as ray tracing a bunch of triangles
• Leads to constant shading and faceted appearance
  – truest view of the mesh geometry
Pipeline for flat shading

• **Vertex stage** (input: position / vtx; color and normal / tri)
  – transform position and normal (object to eye space)
  – compute shaded color per triangle using normal
  – transform position (eye to screen space)

• **Rasterizer**
  – interpolated parameters: $z'$ (screen $z$)
  – pass through color

• **Fragment stage** (output: color, $z'$)
  – write to color planes only if interpolated $z' <$ current $z'$
Result of flat-shading pipeline
Transforming normal vectors

- Transforming surface normals
  - differences of points (and therefore tangents) transform OK
  - normals do not --> use inverse transpose matrix

\[
\begin{align*}
\text{have: } t \cdot n &= t^T n = 0 \\
\text{want: } Mt \cdot X n &= t^T M^T X n = 0 \\
\text{so set } X &= (M^T)^{-1} \\
\text{then: } Mt \cdot X n &= t^T M^T (M^T)^{-1} n = t^T n = 0
\end{align*}
\]
Transforming normal vectors

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Gouraud shading

- Often we’re trying to draw smooth surfaces, so facets are an artifact
  - compute colors at vertices using vertex normals
  - interpolate colors across triangles
  - “Gouraud shading”
  - “Smooth shading”
Gouraud shading

• Often we’re trying to draw smooth surfaces, so facets are an artifact
  – compute colors at vertices using vertex normals
  – interpolate colors across triangles
  – “Gouraud shading”
  – “Smooth shading”
Pipeline for Gouraud shading

• **Vertex stage** (input: position, color, and normal / vtx)
  – transform position and normal (object to eye space)
  – compute shaded color per vertex
  – transform position (eye to screen space)

• **Rasterizer**
  – interpolated parameters: \( z' \) (screen \( z \)); \( r, g, b \) color

• **Fragment stage** (output: color, \( z' \))
  – write to color planes only if interpolated \( z' < \) current \( z' \)
Result of Gouraud shading pipeline
Local vs. infinite viewer, light

- Phong illumination requires geometric information:
  - light vector (function of position)
  - eye vector (function of position)
  - surface normal (from application)

- Light and eye vectors change
  - need to be computed (and normalized) for each vertex
Local vs. infinite viewer, light

• Look at case when eye or light is far away:
  – distant light source: nearly parallel illumination
  – distant eye point: nearly orthographic projection
  – in both cases, eye or light vector changes very little

• Optimization: approximate eye and/or light as infinitely far away
Directional light

• Directional (infinitely distant) light source
  – light vector always points in the same direction
  – often specified by position \([x \ y \ z \ 0]\)
  – many pipelines are faster if you use directional lights
Directional light

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Infinite viewer

• Orthographic camera
  – projection direction is constant

• “Infinite viewer”
  – even with perspective, can approximate eye vector using the image plane normal
  – can produce weirdness for wide-angle views
  – Blinn-Phong: light, eye, half vectors all constant!
Vertex normals

- Need normals at vertices to compute Gouraud shading
- Best to get vtx. normals from the underlying geometry
  - e.g. spheres example
- Otherwise have to infer vtx. normals from triangles
  - simple scheme: average surrounding face normals

\[ N_v = \frac{\sum_i N_i}{\| \sum_i N_i \|} \]
Non-diffuse Gouraud shading

- Can apply Gouraud shading to any illumination model
  - it’s just an interpolation method
- Results are not so good with fast-varying models like specular ones
  - problems with any highlights smaller than a triangle
Per-pixel (Phong) shading

• Get higher quality by interpolating the normal
  – just as easy as interpolating the color
  – but now we are evaluating the illumination model per pixel rather than per vertex (and normalizing the normal first)
  – in pipeline, this means we are moving illumination from the vertex processing stage to the fragment processing stage
Per-pixel (Phong) shading

• Bottom line: produces much better highlights
Pipeline for per-pixel shading

- **Vertex stage** (input: position, color, and normal / vtx)
  - transform position and normal (object to eye space)
  - transform position (eye to screen space)
  - pass through color

- **Rasterizer**
  - interpolated parameters: \( z' \) (screen \( z \)); \( r, g, b \) color; \( x, y, z \) normal

- **Fragment stage** (output: color, \( z' \))
  - compute shading using interpolated color and normal
  - write to color planes only if interpolated \( z' \) < current \( z' \)
Result of per-pixel shading pipeline
Programming hardware pipelines

- Modern hardware graphics pipelines are flexible
  - programmer defines exactly what happens at each stage
  - do this by writing *shader programs* in domain-specific languages called *shading languages*
  - rasterization is fixed-function, as are some other operations (depth test, many data conversions, …)

- One example: OpenGL and GLSL (*GL Shading Language*)
  - several types of shaders process primitives and vertices; most basic is the *vertex program*
  - after rasterization, fragments are processed by a *fragment program*
GLSL Shaders

uniform variables

application

vertex program

rasterizer

fragment program

framebuffer

triangles

attributes

varying parameters

varying parameters

depth

color

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