VGP352 – Week 7

- Agenda:
  - Nonphotorealistic Rendering
    - Cel shading
    - Gooch technical illustration
  - Post-processing, part 1
    - Texture rectangles
    - Full-screen post-processing overview
    - “Ripple” effect

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Non-photorealistic Rendering (NPR)

- From Wikipedia:

  Non-photorealistic rendering (NPR) is an area of computer graphics that focuses on enabling a wide variety of expressive styles for digital art.

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- In other words, NPR attempts to exaggerate or use alternate representations of imagery to convey or highlight a particular mood or message
  - Cel shading (a.k.a. “toon” rendering)
  - Painterly rendering
  - Technical illustrations
  - etc.

Cel Shading

- Several common cartoon image styles:
  - Character regions filled with solid, single-tone colors
  - Regions filled with two tones: light and dark
  - Regions filled with three tones: light, dark, and highlight

Cel Shading

- Several common cartoon image styles:
  - Character regions filled with solid, single-tone colors
  - Regions filled with two tones: light and dark
  - Regions filled with three tones: light, dark, and highlight
  - Each is easy to produce on a computer

Cel Shading

- Single tone coloring

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Cel Shading

- Single tone coloring
  - Solid coloring (flat shading) *without* lighting

Cel Shading

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  - Solid coloring (flat shading) *without* lighting
- Two-tone coloring

Cel Shading

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- Two-tone coloring
  - Driven by surface lighting
  - If lighting is above some threshold, use the lighter color
  - Otherwise use the darker color

Cel Shading

- Single tone coloring
  - Solid coloring (flat shading) *without* lighting
- Two-tone coloring
  - Driven by surface lighting
  - If lighting is above some threshold, use the lighter color
  - Otherwise use the darker color
  - Calculate $\mathbf{n} \cdot \mathbf{l}$ *per vertex* and interpolate across surface, check value per fragment
    - Classically done using texture look-ups, but is faster using conditional assignments on shader hardware

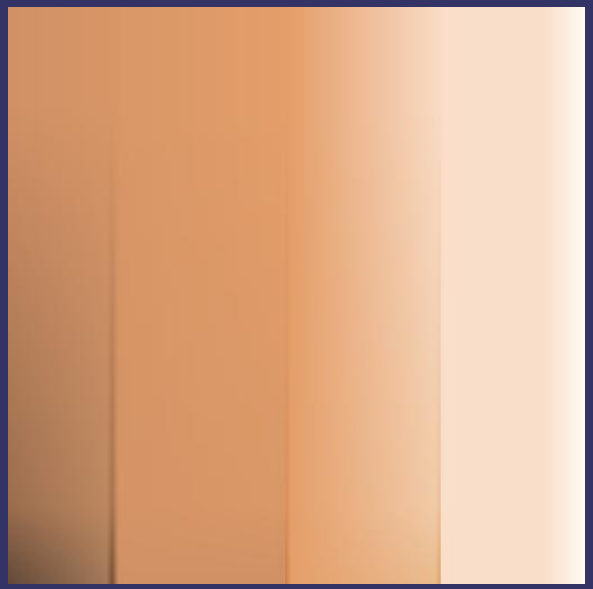
Cel Shading

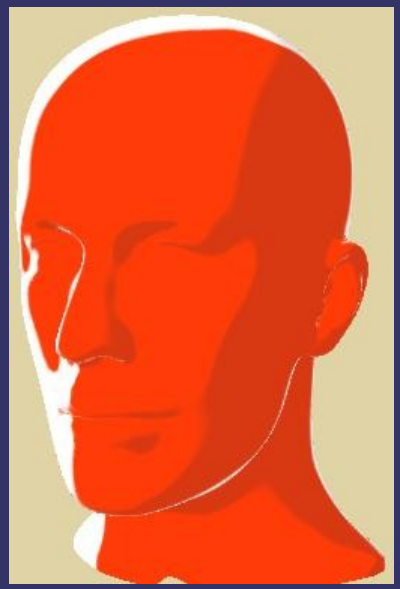
- Shadow-and-highlight method:
  - Calculate $\mathbf{n} \cdot \mathbf{l}$ per vertex
  - Look-up in texture that is half shadow, almost half non-shadow, and a small amount “highlight”
    - Highlight is usually 1 texel

Image from [Lake 2000]

Cel Shading

- X-toon method replaces 1D $\mathbf{n} \cdot \mathbf{l}$ look-up with a 2D $\{\mathbf{n} \cdot \mathbf{l}, (\mathbf{n} \cdot \mathbf{v})^s\}$ look-up
  - Provides a Fresnel-like “rim light” effect





Images from [Barla 2006]

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Cel Shading

- Team Fortress 2 takes this several steps further...

$$\mathbf{k}_{\mathrm{d}}\left[\mathrm{a}(\mathbf{n})+\sum_{\text{all lights}}\mathbf{c}_{\mathrm{i}}\,\mathrm{w}\left(\left(\alpha(\mathbf{n}\cdot\mathbf{l}_i)+\beta\right)^{\gamma}\right)\right]+$$
$$\sum_{\text{all lights}}\left[\mathbf{k}_{\mathrm{s}}\mathbf{c}_{\mathrm{i}}\max\left(f_{\mathrm{s}}(\mathbf{v}\cdot\mathbf{r})^{k_{\text{spec}}},f_{\mathrm{r}}\mathbf{k}_{\mathrm{r}}(\mathbf{v}\cdot\mathbf{r})^{k_{\text{rim}}}\right)\right]+(\mathbf{n}\cdot\mathbf{u})f_{\mathrm{r}}\mathbf{k}_{\mathrm{r}}\mathrm{a}(\mathbf{v})$$

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Light color
Surface specular color
Surface diffuse color

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Directional ambient term

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"Modified" Lambertian term

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Two specular terms!

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Fairly standard specular term

- f_{s} – artist tuned Fresnel term
- k_{spec} – specular from texture or constant

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Rim specular term

- f_{r} – rim Fresnel $(1-(\mathbf{n}\cdot\mathbf{v}))^4$
- k_{rim} – constant rim exponent

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Extra term to make rim highlights come from above

- $\mathbf{u}$ – up vector

References

Lake, A., Marshall, C., Harris, M., and Blackstein, M. 2000. Stylized rendering techniques for scalable real-time 3D animation. In *Proceedings of the 1st international Symposium on Non-Photorealistic Animation and Rendering* (Annecy, France, June 05 - 07, 2000). NPAR '00. ACM, New York, NY, 13-20. http://www.cs.utah.edu/npr/papers/Lake_NPAR00.pdf

Barla, P., Thollot, J., and Markosian, L. 2006. X-toon: an extended toon shader. In *Proceedings of the 4th international Symposium on Non-Photorealistic Animation and Rendering* (Annecy, France, June 05 - 07, 2006). NPAR '06. ACM, New York, NY, 127-132. http://artis.imag.fr/Publications/2006/BTM06a/x-toon.pdf

Mitchell, J. L., Francke, M., and Eng, D. 2007. Illustrative rendering in Team Fortress 2. In *ACM SIGGRAPH 2007 Courses* (San Diego, California, August 05 - 09, 2007). SIGGRAPH '07. ACM, New York, NY, 19-32. http://www.valvesoftware.com/publications.html

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  - Material edge – boundary between two different colors or materials
  - Silhouette edges – edges where one border polygon faces towards the viewer and the other faces away

Cel Boundary Inking

- Most boundary types are calculated during authoring or as a pre-processing step
  - Border edges – edges are added by the artist, by the authoring tool, or are detected in a pre-processing step
  - Crease edges – dihedral angle is calculated during pre-processing. If $\mathbf{n}_{surface1} \cdot \mathbf{n}_{surface2} < \cos(60^\circ)$, the edge is a crease
  - Material edge – handled the same as border edges

Silhouette Edge Rendering

- Silhouette edges are view-dependent and must be calculated at run-time
  - Conceptually similar to drawing fins in shells-and-fins fur rendering
- Several broad classes of implementations:
  - Surface angle
  - Added geometry
  - Image processing
  - Explicit edge detection

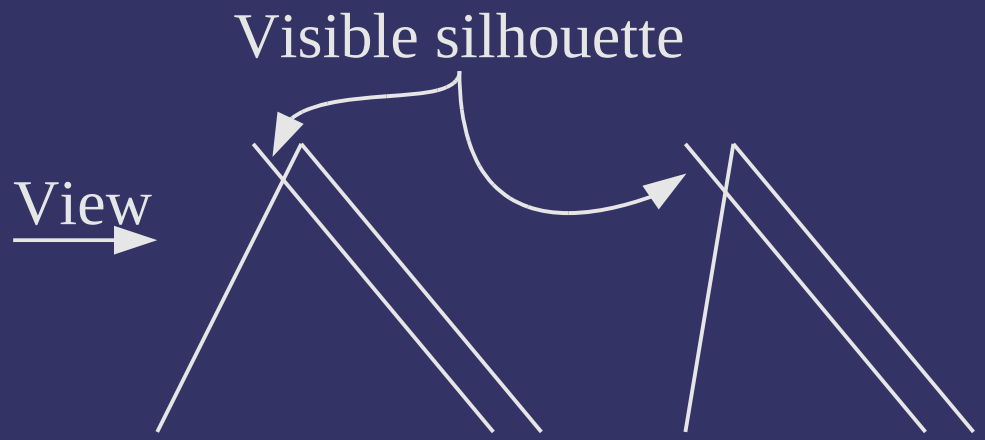
Silhouette Edge Rendering

- Surface angle test is similar to two-tone cel shading
  - Examine angle between $\mathbf{v}$ and $\mathbf{n}$
  - If angle is near 90°, use silhouette color
- Pros / cons:
  - *Really* easy to implement
  - Doesn't work on all models
    - Generally fails on models with large flat surfaces
    - Only worked on about 25% of the models in the game *Cel Damage*[1]

[1] *Real-Time Rendering*, p. 295

Silhouette Edge Rendering

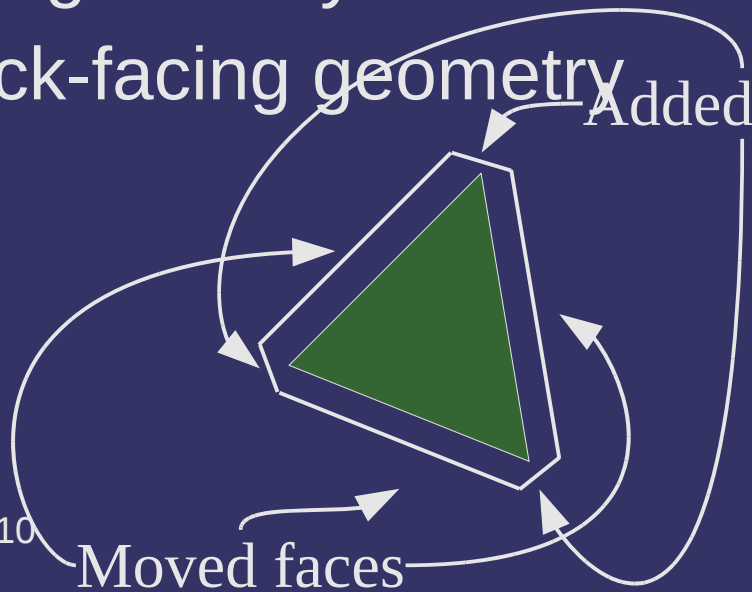
- Back-face biasing:
  - Render back-facing geometry by moving it towards the camera by some small delta



  - Amount to bias back-face depends on both slope of back-face and slope of front-face

Silhouette Edge Rendering

- Edge expansion:
  - Move each face out by some distance along the plane's normal
    - *Not* the vertex normal!
    - Adjust the distance according to the desired silhouette thickness
  - Create new geometry to fill in the gaps
  - Render back-facing geometry



Silhouette Edge Rendering

- Shell expansion:
  - Similar to edge expansion
  - Render shell as object geometry expanded along vertex normals
    - Normals must be identical for vertices shared by two polygons
    - Otherwise degenerate edge polygons must be added
    - Render only back-faces of shell

Silhouette Edge Rendering

- Image processing:
  - Render surface normal and depth a texture
    - Store normal in RGB and most significant portion of depth in alpha
  - Process texture with separable edge detection filter
    - Card and Mitchell recommend using the Sobel edge detection filter
    - Store each pass in a texture
    - Composite both textures together over scene

Silhouette Edge Rendering

- Explicit edge detection:
  - Draw each edge of the object as a line
  - At each vertex, store the normals of the two adjoining polygons
  - If one normal points towards the viewer and the other away, draw the line as a silhouette
  - If the two normals point significantly away from each other, draw the line as a crease

Gooch-style Technical Illustration

- Many similar ideas to cel shading
  - Use alternate shading
  - Highlight creases
  - Highlight silhouettes

Gooch-style Technical Illustration

- Shade objects from warm to cool instead of light to dark
  - Still conveys information about the curvature of the object
  - Maintains visibility of details in areas that would be dark or difficult to light

Gooch-style Technical Illustration

- Shade objects from warm to cool instead of light to dark
  - Still conveys information about the curvature of the object
  - Maintains visibility of details in areas that would be dark or difficult to light
- Shade in similar manner to cel shading
  - Calculate $\mathbf{n} \cdot \mathbf{l}$ per vertex
  - Use interpolated value per fragment to look up in a 1D blue-green to yellow-orange gradient texture

Gooch-style Technical Illustration

- Draw crease edges in white
  - This helps provide information about the model's orientation

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Gooch-style Technical Illustration

- Draw crease edges in white
  - This helps provide information about the model's orientation
- Draw silhouette edges in black
  - If an edge is *both* a crease and a silhouette, it should be drawn as a silhouette
- Silhouette and crease edges are handled differently, so the image processing method of inking probably can't be used
  - Using the explicit edge detection method allows silhouettes and creases to be drawn in a single pass

References

Gooch, B., Sloan, P. J., Gooch, A., Shirley, P., and Riesenfeld, R. 1999. Interactive technical illustration. In *Proceedings of the 1999 Symposium on interactive 3D Graphics* (Atlanta, Georgia, United States, April 26 - 29, 1999). I3D '99. ACM, New York, NY, 31-38. http://www.cs.utah.edu/~bgooch/ITI/

Texture Rectangle

- Cousin to 2D textures
  - Interface changes:
    - New texture target: `GL_TEXTURE_RECTANGLE_ARB`
    - New sampler type: `sampler2DRect`, `sampler2DRectShadow`
    - New sampler functions: `texture2DRect`, `texture2DRectProj`, etc.
  - Limitations:
    - No mipmaps
    - Minification filter must be `GL_LINEAR` or `GL_NEAREST`
    - Wrap mode must be one of `GL_CLAMP_TO_EDGE`, `GL_CLAMP_TO_BORDER`, or `GL_CLAMP`

Texture Rectangle

- Added features:
  - Dimensions need not be power of two
    - Alas, now only a “feature” on old hardware
  - Accessed by non-normalized coordinates
    - Coordinates are $[0, w] \times [0, h]$

Post-processing Effects

- Apply an *image space* effect to the rendered scene *after* it has been drawn
  - Examples:
    - Blur
    - Enhance contrast
    - Heat “ripple”
    - Color-space conversion (e.g., black & white, sepia, etc.)
    - Many, *many* more

Post-processing Effects

- Overview:
  - Render scene to off-screen target (framebuffer object)
    - Off-screen target should be same size as on-screen window
    - Additional information may need to be generated
  - Render single, full-screen quad to window
    - Use original off-screen target as source texture
    - Configure texture coordinates to cover entire texture
      - Texture rectangles are *really* useful here
    - Configure fragment shader to perform desired effect

Post-processing Effects

- Configure projection matrix to remap [0, 0] $\times$ [w, h] to [-1, 1] $\times$ [-1, 1] with parallel perspective

$$\begin{bmatrix} \frac{2}{width} & 0 & 0 & -1 \\ 0 & \frac{2}{height} & 0 & -1 \\ 0 & 0 & -1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

  - This is the same as the old `glOrtho` function

Post-processing Effects

- Draw two full-screen triangles
  - Use pixel coordinates for both vertex positions and texture coordinates
  - This assumes texture rectangles are being used

Post-processing Effects

- May need to access many neighbor texels in the fragment shader
  - Can calculate these coordinates in the fragment shader, but this uses valuable instructions
  - Instead use all of the available varying slots and pre-calculate offset coordinates in the vertex shader
    - Query `GL_MAX_VARYING_FLOATS` to determine how many slots are available

Post-processing Effects

- Offset texel locations can also be accessed with `textureOffset` and friends

```
vec4 textureOffset(sampler2D s, vec2 p,
    ivec2 offset);
```

  - Integer offset must be known at *compile* time
  - Requires GLSL 1.30.
  - Available with `EXT_gpu_shader4` as `texture2DOffset`, `texture2DRectOffset`, etc.

Ripple Effect

Note the frame-to-frame difference

Image from Enemy Territory: Quake Wars, © Copyright 2007 id Software, Inc.

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Ripple Effect

- Render multiple passes:
  1) Render scene normally to one texture
  2) Render water surface to a separate texture
     - Instead of color, render a perturbation vector
     - Clear color is a perturbation vector of {0, 0}
  3) Render final scene by using water texture to select texels from scene texture
  4) Render water over final scene

Ripple Effect

Note the bleeding of out-of-water elements into the ripples

Image from Enemy Territory: Quake Wars, © Copyright 2007 id Software, Inc.

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Optimization

- Multiple texture look-ups for ever pixel can be expensive

Optimization

- Multiple texture look-ups for ever pixel can be expensive
  - Can render “effect area” to stencil buffer
  - Perform combine step in two passes:
    - First pass just copies areas where stencil is not set
    - Second pass performs effect in areas where stencil is set
  - Can be extended to select multiple screen-space effects using different stencil values

References

Tutorials for several post-processing effects:

http://www.geeks3d.com/20091116/shader-library-2d-shockwave-post-processing-filter-glsl/

Next week...

- More post-processing effects
  - General image filters
  - Separable filters
  - Depth-of-field
  - High dynamic range (HDR) rendering

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