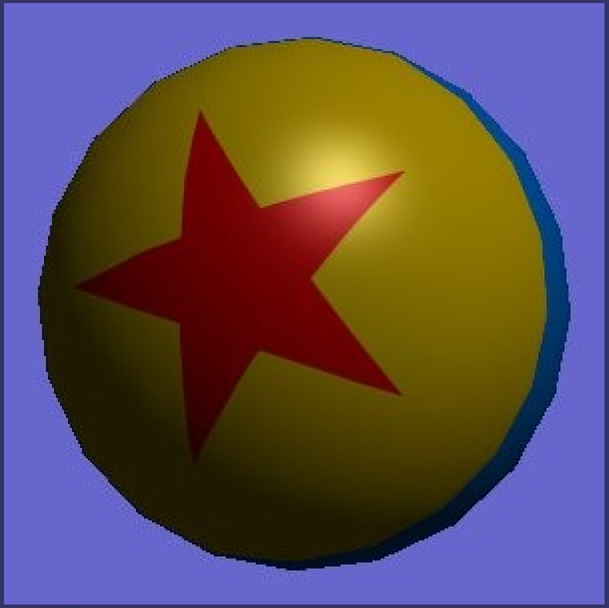
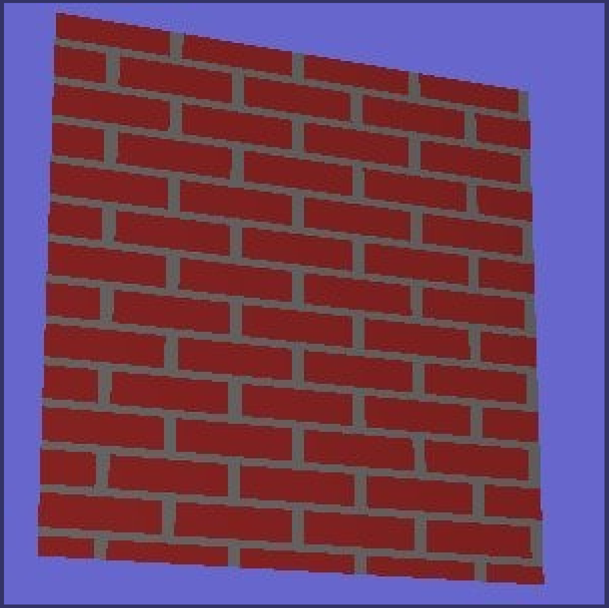
VGP352 – Week 2

- Agenda:
  - Procedural texturing and modeling
    - Rationale
    - Basic techniques / examples
    - Noise
    - Anti-aliasing

Procedural Graphics

- Generation of textures, models, or animation from *code* instead of *data*
  - Creation may happen at rendering-time *or* at application load-time





Procedural Graphics

- Why?
  - Less space!
  - Easier to add “random” variation
  - May be easier to describe than to draw
    - L-systems for trees
    - Fractals for whole worlds
    - etc.

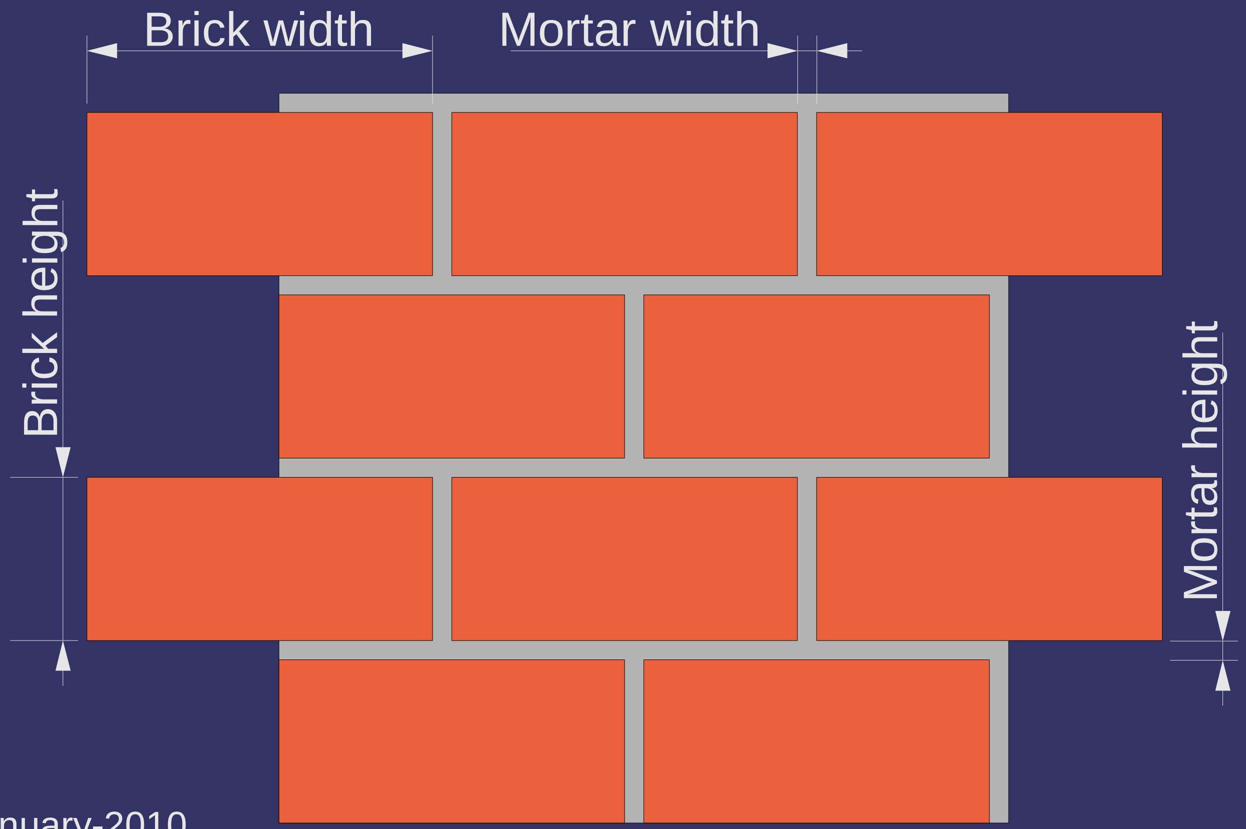
Procedural Graphics

- Example: “Debris” by Farbrausch
  - Entire demo is 181,248 bytes
  - This JPEG image is 166,059 bytes!

  - See http://scene.org/file.php?id=373930 or http://www.youtube.com/watch?v=wqu_IpkOYBg&fmt=22

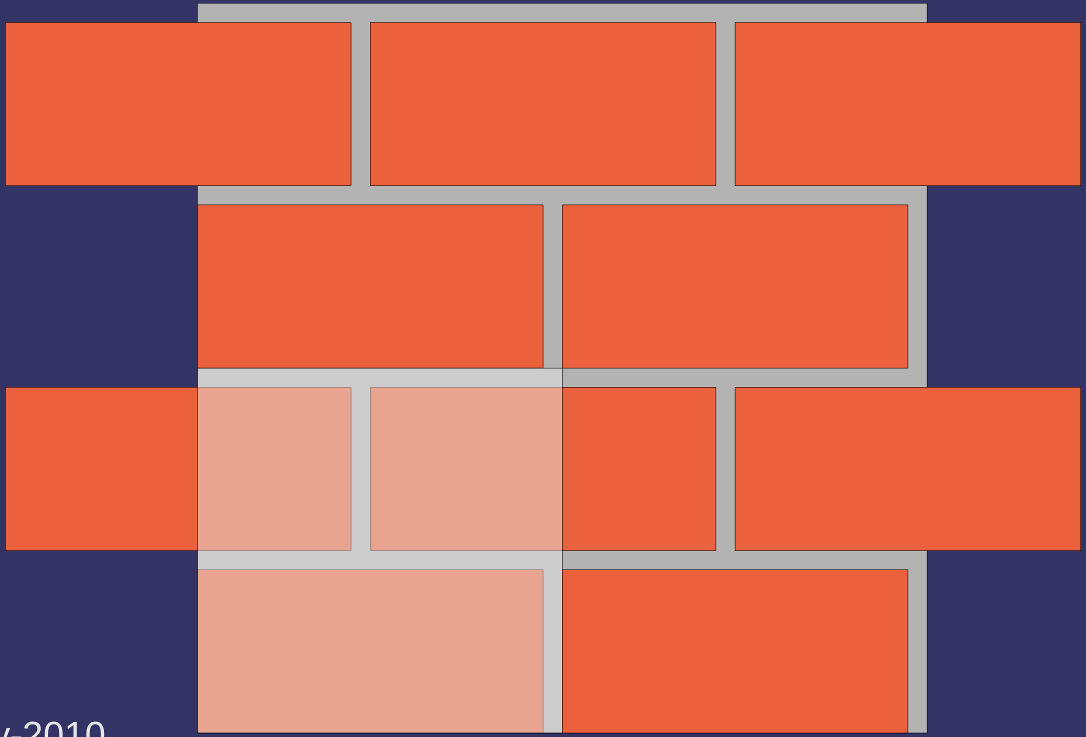
Brick Shader

- Given some parameters, generate an image that looks like bricks



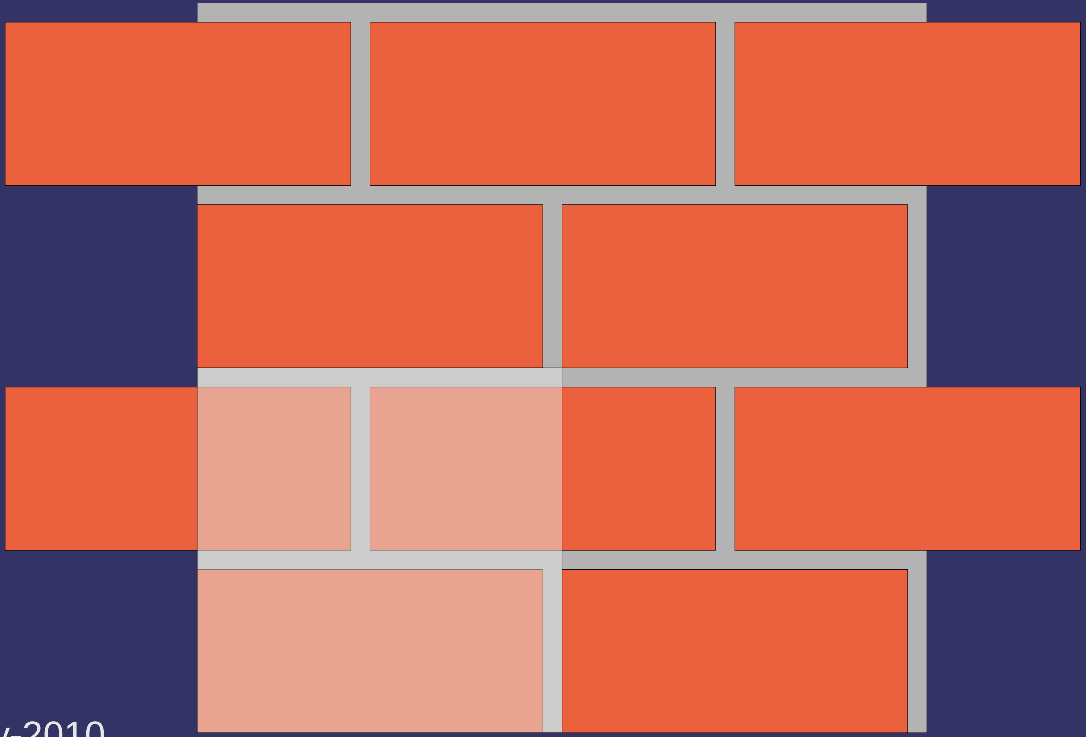
Brick Shader

- Given some parameters, generate an image that looks like bricks
  - Divide *shader-space* into cells
  - Each cell is conceptually a 1×1 unit



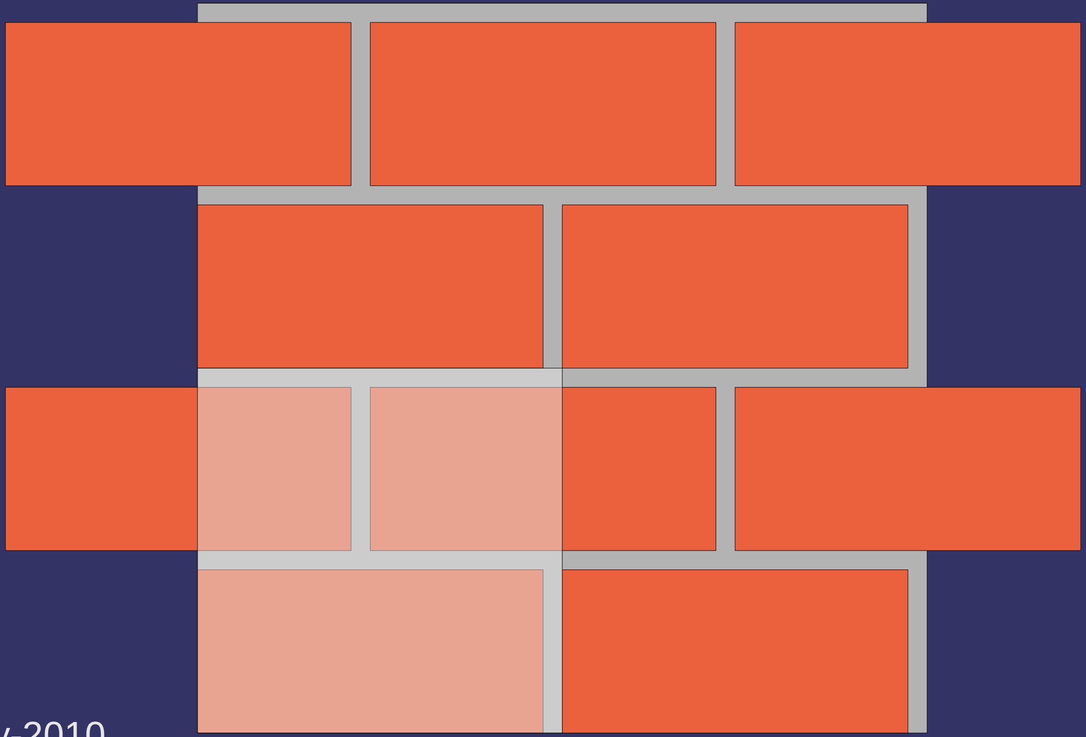
Brick Shader

- Bottom row is easy:
  - If `s` is less than `brick_width / (brick_width + mortar_width)`, the color is brick



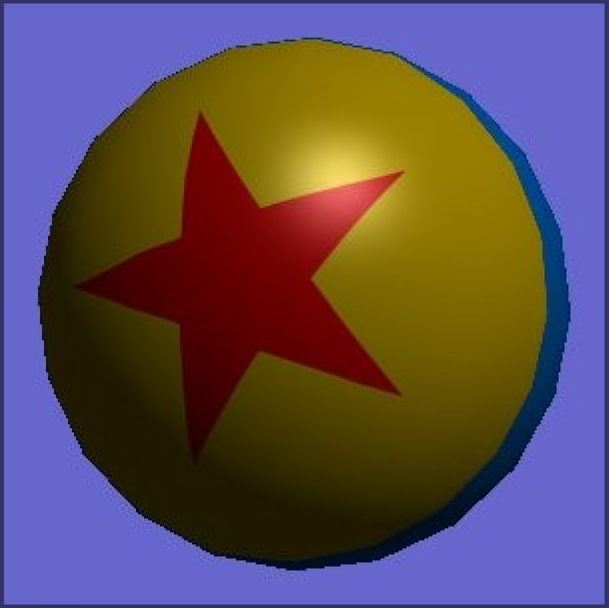
Brick Shader

- Top row is the bottom row with an offset
  - If `t` is greater than `brick_height / (brick_height + mortar_height)`, add 0.5 to `s`



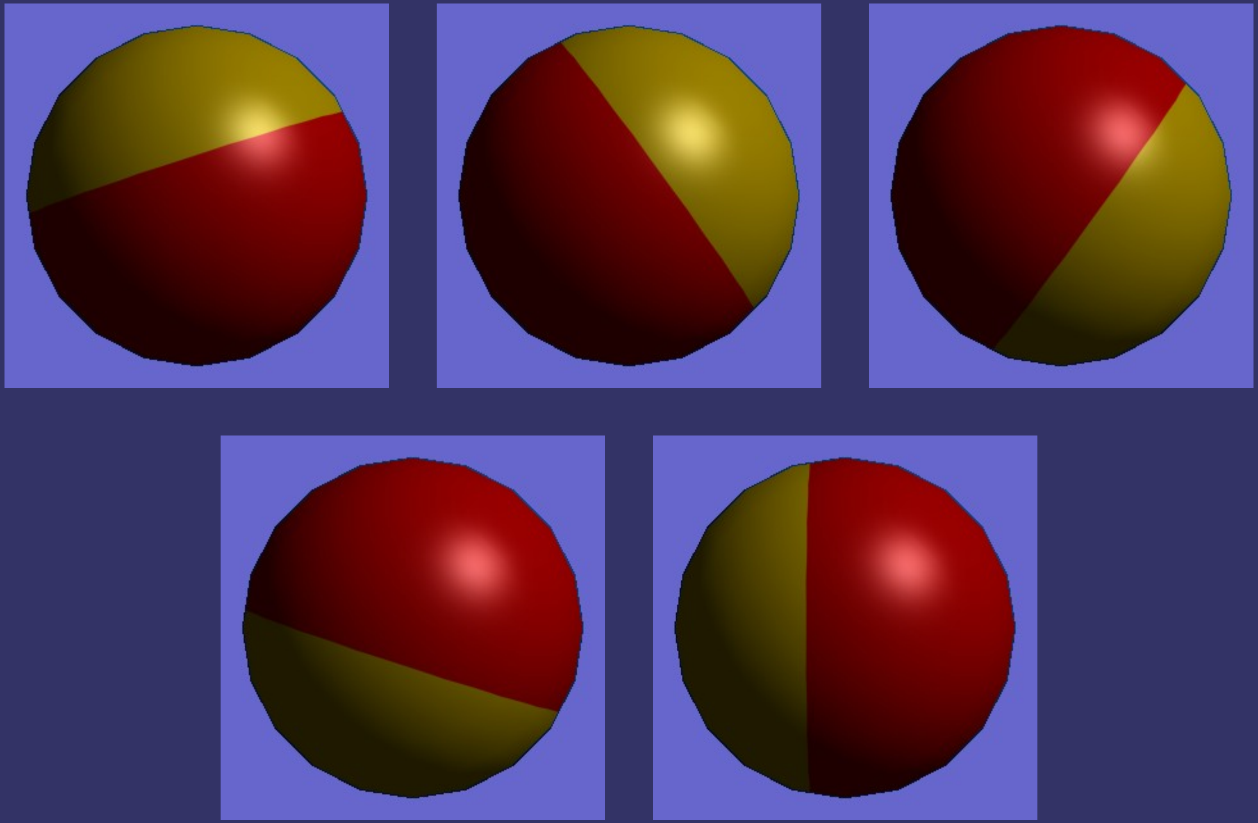
Toy Ball

- Texture consists of a complex shape
  - Can't use simple compares to determine which region a point is in
  - All of the boundaries are straight lines



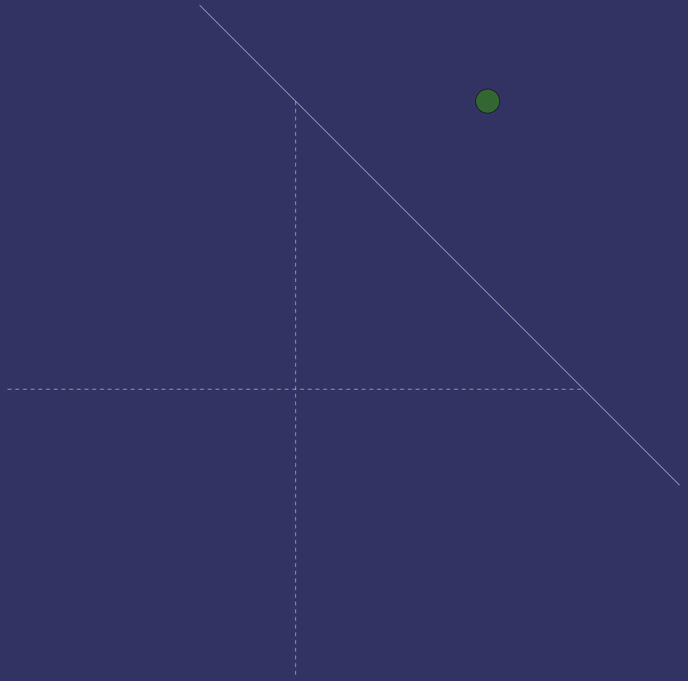
Toy Ball

- Divide shader space into regions called *half spaces*



Toy Ball

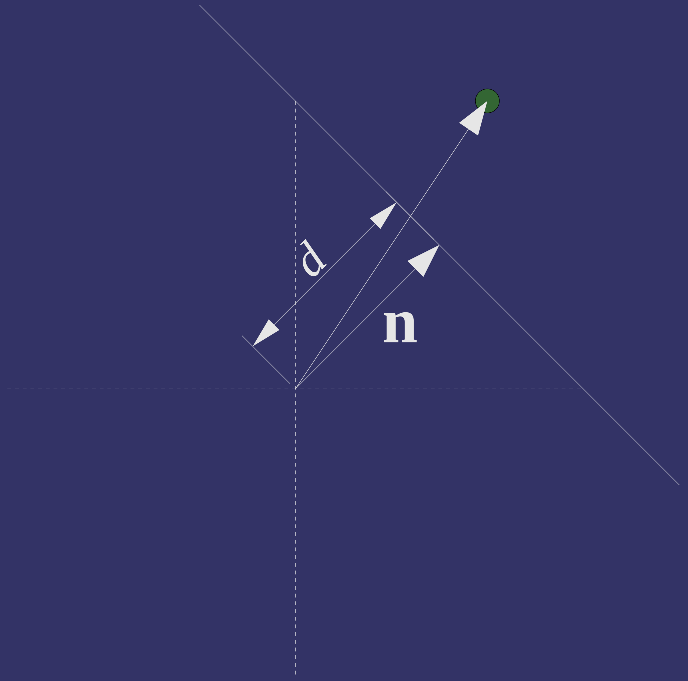
- If we draw a line through 2D space, how do we determine which side of that line a point is on?



Toy Ball

- If we draw a line through 2D space, how do we determine which side of that line a point is on?
  - Use the parametric definition of a line
  - Use *x* and *y* from the point
    - If the result is less than 0, the point is “inside”
    - If the result is equal to 0, the point is on the line
    - If the result is greater than 0, the point is “outside”

$$\mathbf{o} = ax + by - d$$



Toy Ball

- What does this look like?

$$a x + b y - d$$

Toy Ball

- What does this look like?

$$a x + b y - d$$

- Our friend, the dot-product:

$$\begin{bmatrix} a & b & -d \end{bmatrix} \cdot \begin{bmatrix} x & y & \mathbf{q} \end{bmatrix}$$

Toy Ball

- We want a binary answer whether the point is inside or outside

```
dist = dot(p, half_space);
in_or_out = (dist < 0.0) ? 0.0 : 1.0;
```

  - A more succinct way in GLSL uses the `step` function:

```
dist = dot(p, half_space);
in_or_out = step(0.0, dist);
```

Toy Ball

- We want a binary answer whether the point is inside or outside of all 5 half-spaces

```
dist.x = dot(p, half_space0);
dist.y = dot(p, half_space1);
dist.z = dot(p, half_space2);
dist.w = dot(p, half_space3);

dist.x = step(dot(dist, vec4(1.0))) +
    step(0.0, dot(p, half_space4));

in_or_out = dist.x > 4.0;
color = mix(ball_color, star_color, in_or_out);
```

References

http://www.wired.com/gaming/gamingreviews/magazine/16-08/pl_games

http://people.freedesktop.org/~idr/GLSL_presentation/GLSL-Portland-Bill.PPT

Wang Tiles

- Goal: we want to create an infinite, non-repeating texture for things like grass, sand, etc.

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  - *And* it will use 16MB of texture memory...yuck!

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- Create a “mosaic” from small a few small “tiles”

Wang Tiles

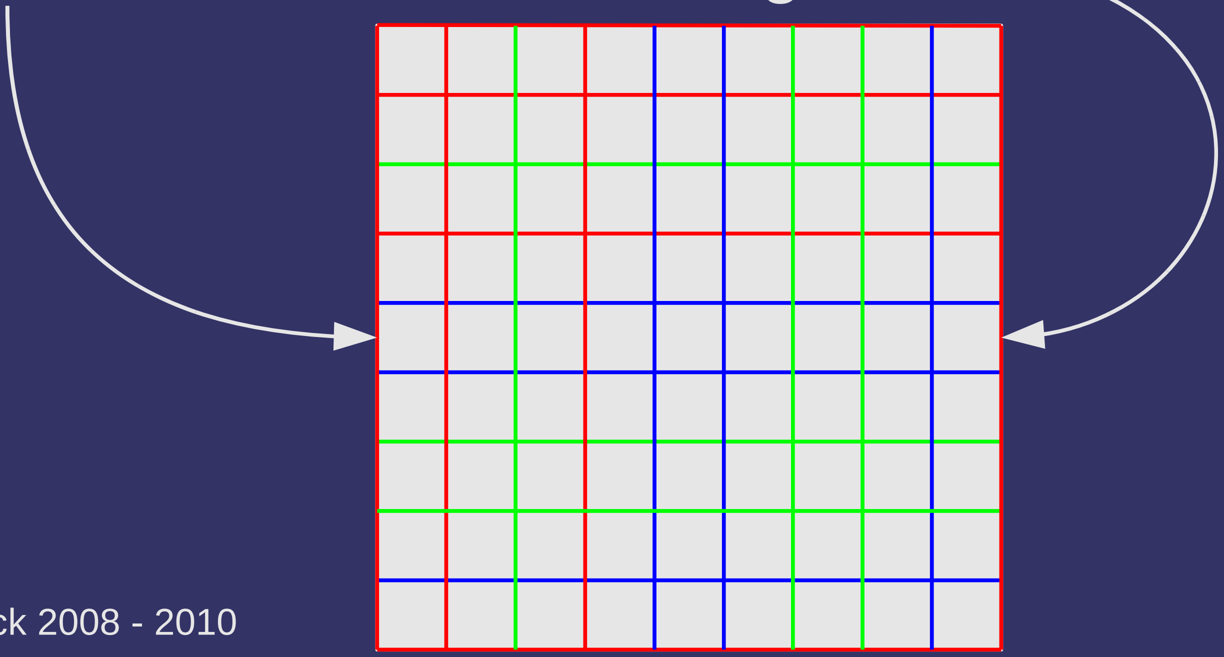
- Goal: we want to create an infinite, non-repeating texture for things like grass, sand, etc.
  - Even a 2048x2048 texture will show tiling artifacts
  - *And* it will use 16MB of texture memory...yuck!
- Create a “mosaic” from small a few small “tiles”
  - If the tile selection is pseudo-random, as few as 32 tiles can have a *very* large repeat period
  - Unlike mosaic tiles, texture tiles have to match at the edges
    - Either all tiles edges have to match or the selection algorithm has to pick a tile that will match edges with its neighbors

Wang Tiles – Edge Coloring

- Name the four tile edges N, E, S, W
  - The N/S edges can have one of K_v edge “colors”
  - The E/W edges can have one of K_h edge “colors”
    - A tile with an N edge of color X must be south of a tile with an S edge of color X
  - A tile with each possible combination of edge colors must exist
    - There must be at least $K_v^2 \times K_h^2$ tiles

Wang Tiles – Tile Arrangement

- Assuming we have a set of tiles...
  - Generating tiles from a sample source image is a larger topic than we have time for
- Arrange tiles in a $K_v^2 \times K_h^2$ pattern in texture atlas
  - Neighboring tiles must obey edge coloring rules...even neighbors across border edges!



Wang Tiles – Tile Arrangement

- Given a pair of edge colors, the following placement algorithm is use:

$$Index(e_1, e_2) = \begin{cases} 0 & if\ e_1 = e_2 = 0 \\ e_1^2 + 2e_2 - 1 & if\ e_1 > e_2 > 0 \\ e_2^2 + 2e_1 & if\ e_2 > e_1 \geq 0 \\ (e_2 + 1)^2 - 2 & if\ e_1 = e_2 > 0 \\ (e_1 + 1)^2 - 1 & if\ e_1 > e_2 = 0 \end{cases}$$

Wang Tiles – Tile Selection

- Given texture coordinate (s, t):
  - Calculate tile index
    - $O_h = t / T_h$
    - $O_v = s / T_v$
  - Hash tile index to calculate edge colors
    - $C_s = H(H(O_h) + O_v) \% K_v$
    - $C_n = H(H(O_h) + O_v + 1) \% K_v$
    - $C_w = H(O_h + H(O_v * 2)) \% K_h$
    - $C_e = H(O_h + 1 + H(O_v * 2)) \% K_h$
    - Notice that $C_e(x, y) = C_w(x + 1, y)$
  - Convert edge colors to row / column indexes

Wang Tiles – Tile Selection

- Given texture coordinate (s, t):
  - Calculate row / column position in texture
    - $t_{base} = I_h * T_h$
    - $s_{base} = I_v * T_v$
  - Calculate texel offset within tile
    - $t_{offset} = t \% T_h$
    - $s_{offset} = s \% T_v$
  - Sample the texture!
    - Final coordinate is ($s_{base} + s_{offset}$, $t_{base} + t_{offset}$)

Wang Tiles – Hash Function

- Implement as a permutation table
  - Use a texture rectangle that is 1 texel tall
    - Use roughly 4x entries in table as possible edge colors
  - More recent hardware can use uniform arrays
    - Geforce 6 or Radeon X800

Wang Tiles – Filtering Gotchas

- Mipmap filtering can be a problem...
  - The 1x1 level blends all of the tiles together...bad!!!
    - Need to clamp the minimum LOD to the level lowest level that doesn't blur across tile boundaries
    - The tile map is just a big texture atlas
  - This is *much* easier with texture arrays

References

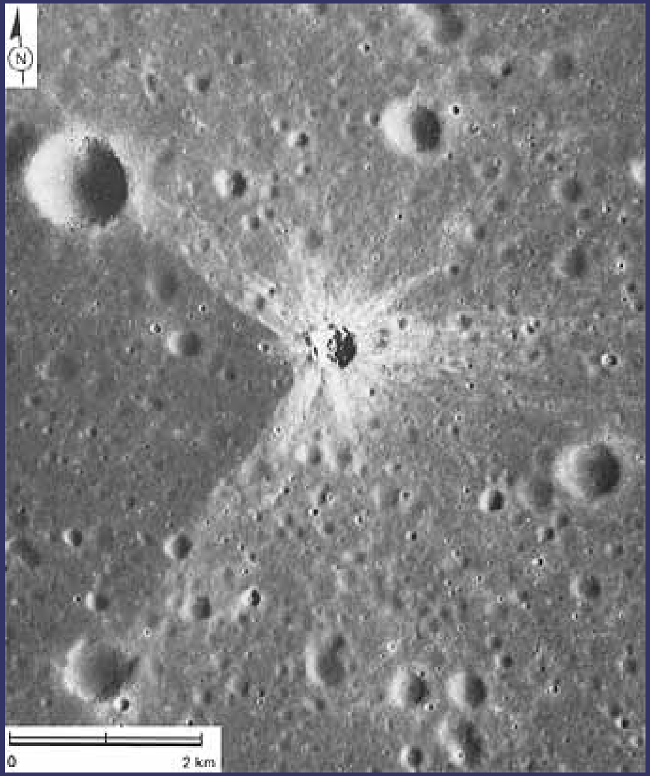
http://en.wikipedia.org/wiki/Wang_tile

Wei, L. “Tile-based texture mapping on graphics hardware.” In *ACM SIGGRAPH 2004 Sketches* (Los Angeles, California, August 08 - 12, 2004). R. Barzel, Ed. SIGGRAPH '04. ACM, New York, NY, 67. http://graphics.stanford.edu/papers/tile_mapping_gh2004/

Wei, L. “Tile-Based Texture Mapping.” In GPU Gems 2. Ed. Matt Pharr. Upper Saddle River, NJ: Pearson Education, Inc., April 2005. http://http.developer.nvidia.com/GPUGems2/gpugems2_chapter12.html

Crater Shader

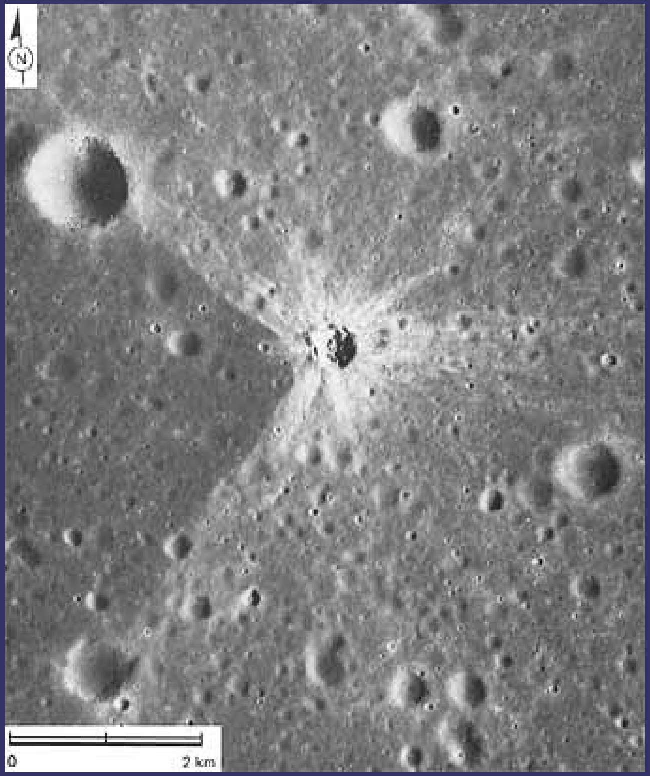
- Task: create a procedural texture for impact craters on, for example, the moon



Original image from http://www.hq.nasa.gov/office/pao/History/SP-362/ch5.2.htm

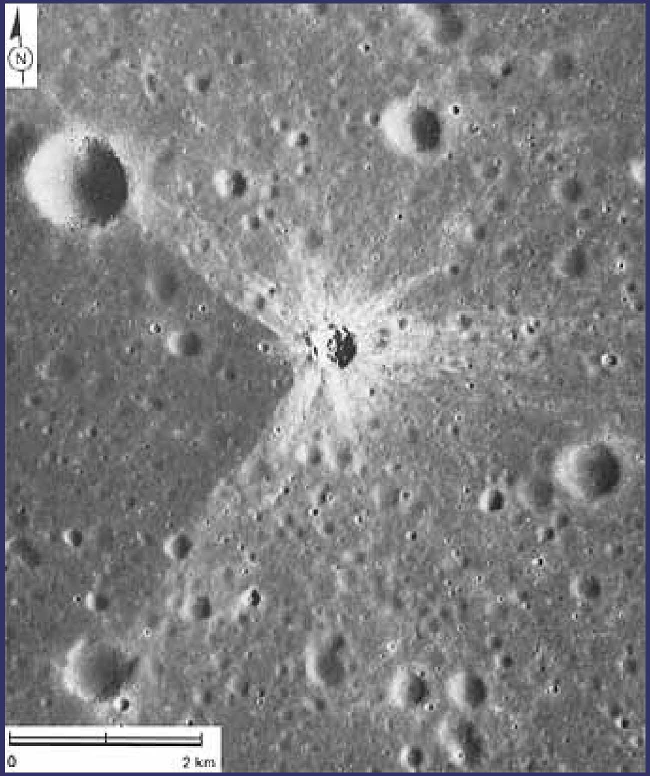
Crater Shader

- Two parts to this shader



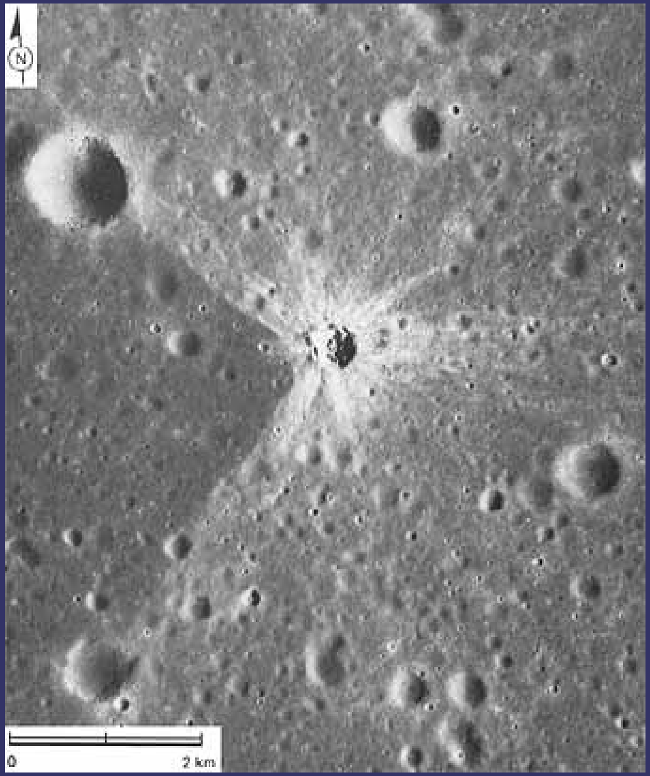
Crater Shader

- Two parts to this shader
  - Height / normal
  - Color



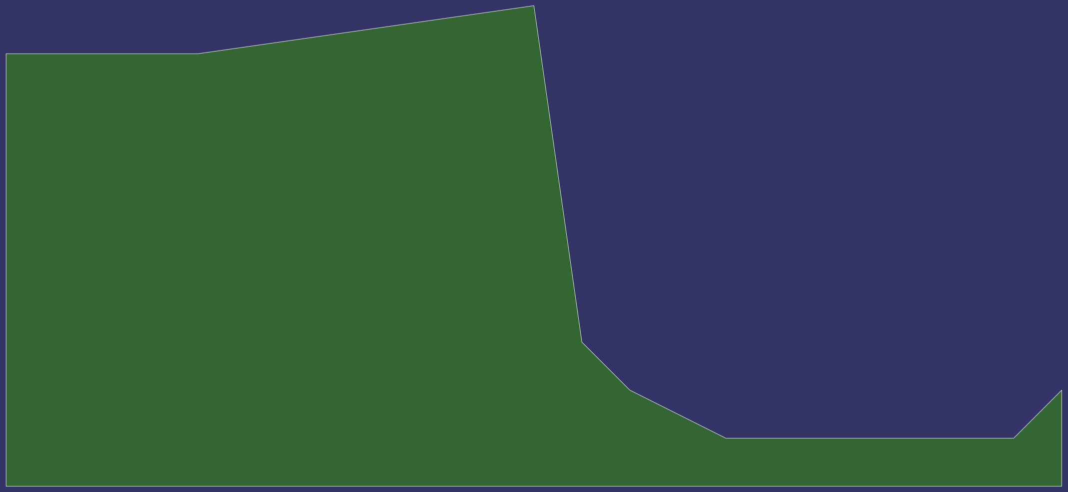
Crater Shader

- Two parts to this shader
  - Height / normal
  - Color
  - Attack each separately, then try to unify



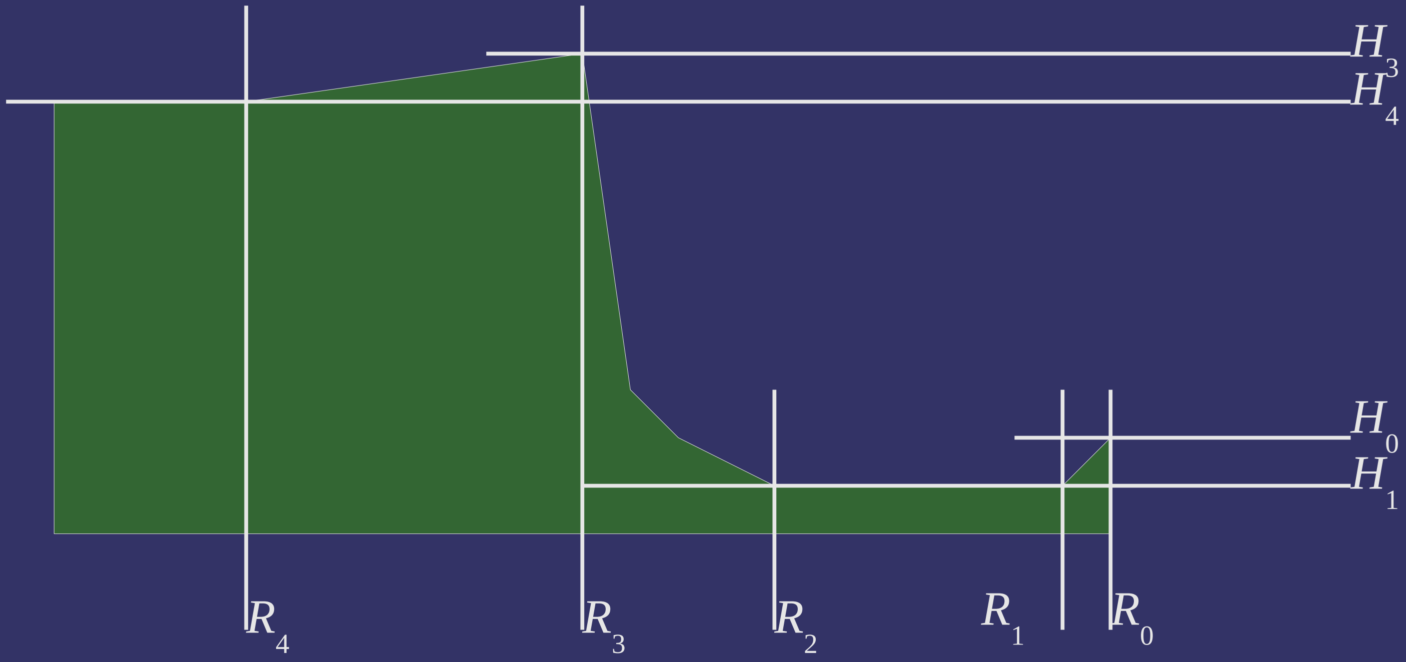
Crater Shader – Height

- Craters are generally circular
  - Height varies with distance from center



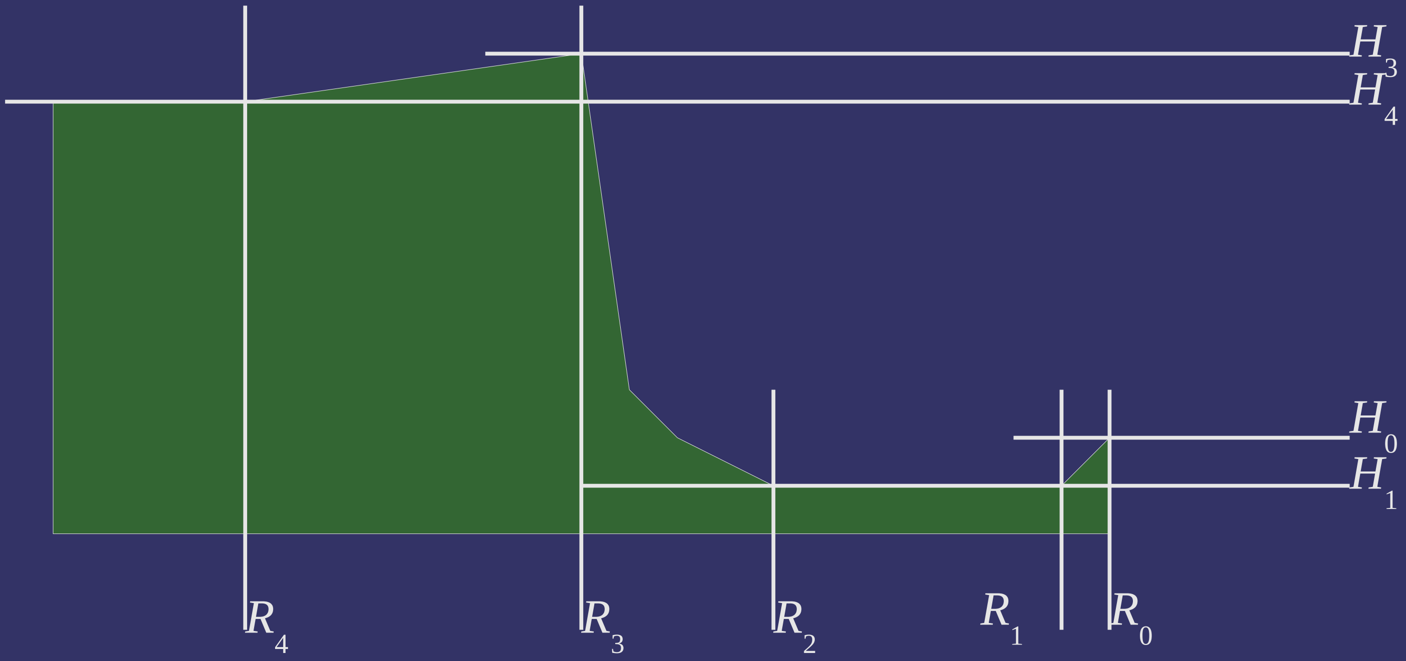
Crater Shader – Height

- Craters are generally circular
  - Height varies with distance from center
  - Associate a height with each distance where there is a change



Crater Shader – Height

- Select an interpolation scheme between each region
  - R_0 to R_1 and R_1 to R_2 could be linear, R_2 to R_3 and R_3 to R_4 could be exponential, etc.



Crater Shader – Height

- In shader:
  - Determine fragment distance from center

```
r = length(position – center);
```

Crater Shader – Height

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  - Determine which region contains the fragment

```
if (r < crater_param[1].x) {
    ...
} else if (r < crater_param[2].x) {
    ...
} else ...
```

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if (r < crater_param[1].x) {
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} else ...
```

  - Determine fragment location in region

```
t = (r – crater_param[n].x)
 / (crater_param[n+1].x - crater_param[n].x);
```

Crater Shader – Height

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  - Determine fragment distance from center

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```

  - Determine fragment location in region

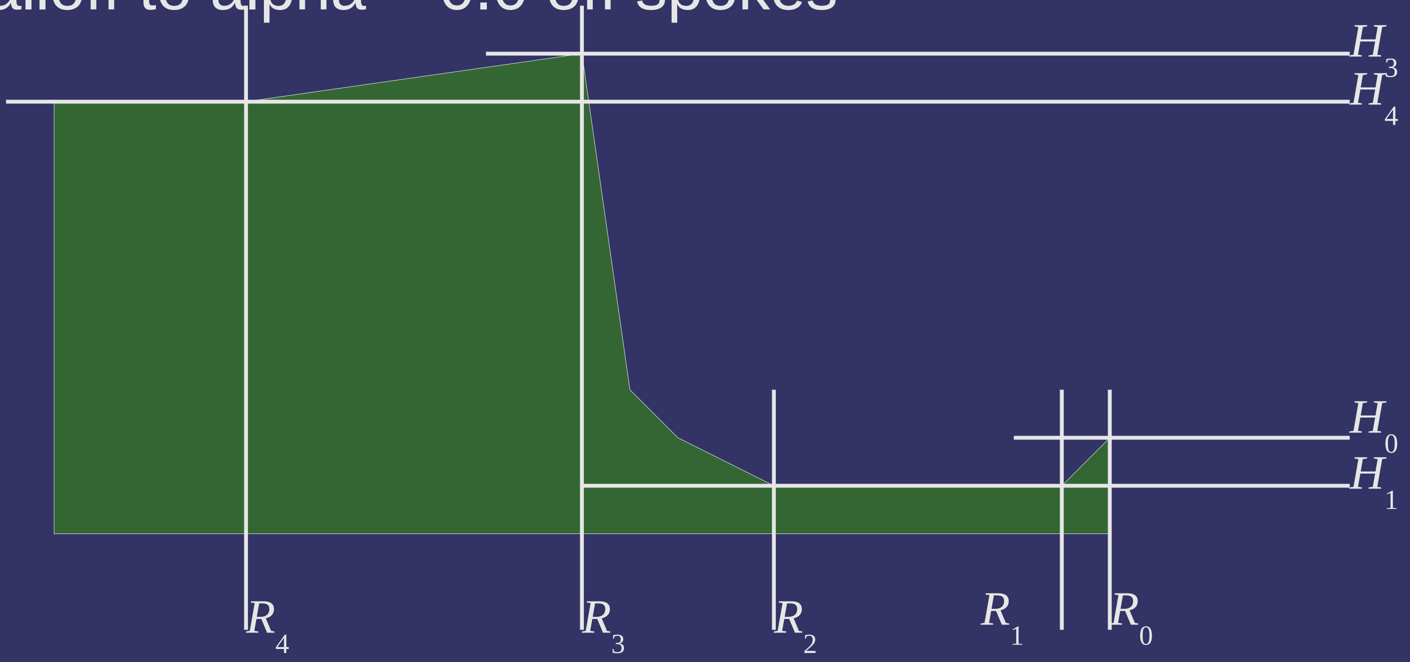
```
t = (r – crater_param[n].x)
  / (crater_param[n+1].x - crater_param[n].x);
```

  - Perform interpolation

```
h = mix(crater_param[n+1].y, crater_param[n].y, t);
```

Crater Shader – Color

- Color works in a similar manner
  - Use one color inside the crater with alpha set to 1.0
  - Use another color outside the crater
    - Set alpha to 1.0 in “spokes” from crater
    - Falloff to alpha = 0.0 off spokes



Crater Shader – Color

- Selecting crater interior color is trivial
  - If r is less than R_3, use interior color

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- Selecting spoke color is more complex
  - Need to know distance from center *and* angle (i.e., polar coordinates)
  - Place spokes separated by fixed angles
    - Spokes are determined by a cosine wave in polar coordinates
    - $r_{spoke} = \cos(\alpha \times frequency)$

Crater Shader – Color

- Selecting crater interior color is trivial
  - If r is less than R_3, use interior color
- Selecting spoke color is more complex
  - Need to know distance from center *and* angle (i.e., polar coordinates)
  - Place spokes separated by fixed angles
    - Spokes are determined by a cosine wave in polar coordinates
    - $r_{spoke} = \cos(\alpha \times frequency)$
  - Select random length and thickness for each spoke
    - Noise to the rescue
    - Thickness is determined by raising $(r_{spoke} \times amplitude)$ to a power

References

Ebert, David, et. al., *Texturing and Modeling: A Procedural Approach*, second edition, Morgan-Kaufmann, 1998. pp. 315 – 318.

- This section provided the inspiration for the crater shader.

Brief history of noise

- Developed by Ken Perlin in the early 80s
  - Ken worked on the revolutionary graphics for the movie *Tron*
  - Frustrated that *Tron's* graphics looked so “machine-like,” he wanted to escape the "machine-look ghetto."
- *Tron* was *not nominated* for the Academy Award for Special Effects
  - It “cheated” by using computers
  - What movie won?

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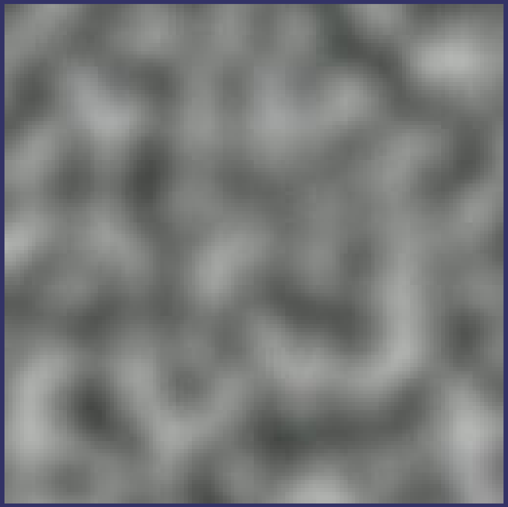
  - It “cheated” by using computers
  - What movie won?
    - *E.T. the Extra Terrestrial* won, defeating *Blade Runner* and *Poltergeist*

Brief history of noise

- In 1983 Perlin worked on creating a space filling, apparently random signal function
  - Appear random
  - Be controllable
  - All features to be approximately the same size
  - All the features to be roughly isotropic
  - Have a range [-1, 1]
- First presented as a course at SIGGRAPH '84
  - The paper followed at SIGGRAPH '85
  - The Academy Award for Technical Achievement followed in 1997

Using Noise

- In Perlin's words, “noise is salt for graphics.”
  - Salt by itself is boring
  - Without salt, food is boring too



Original image from http://en.wikipedia.org/wiki/Perlin_noise

Using Noise

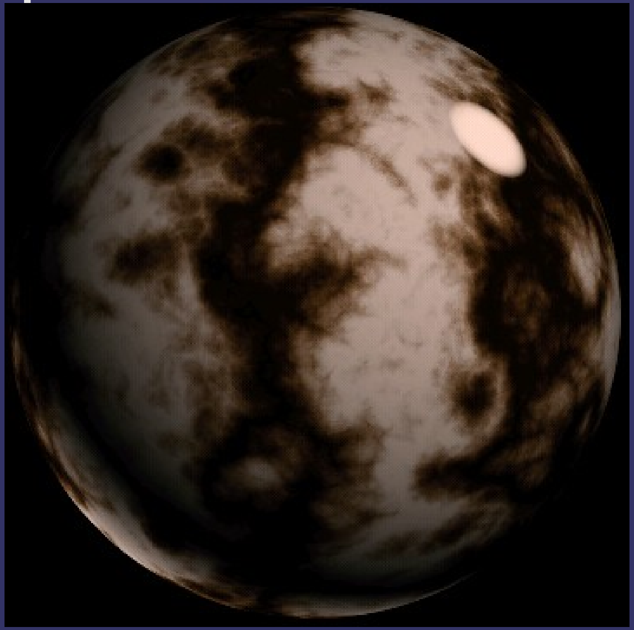
- Noise is typically used in multiple frequencies
  - Each frequency band is called an *octave*
  - As octave frequency increases, the amplitude decreases

$$NOISE(p) = \sum_{i=0}^{N-1} \frac{noise(f_i p)}{a_i}$$

Using Noise

- Add noise to boring functions or textures to make them interesting
  - Marble is the *classic* example

$$\sin\left(x+\left|NOISE\left(y\right)\right|\right)$$



Original image from http://www.noisemachine.com/talk1/23.html, copyright Ken Perlin

Implementing Noise

- Use GLSL noise function
  - Most (all?) implementations are *really* bad
  - Some just return a constant value for all inputs!

Implementing Noise

- Implement noise in C, generate noise texture
  - Tiling artifacts
  - Consumes texture resources

Implementing Noise

- Implement noise in GLSL code
  - Several implementations exist:

    Green, Simon. “Implementing Improved Perlin Noise.” GPU Gems 2. Ed. Matt Pharr. Upper Saddle River, NJ: Pearson Education, Inc., April 2005. http://http.developer.nvidia.com/GPUGems2/gpugems2_chapter26.html

    Olano, Marc. “Modified Noise for Evaluation on Graphics Hardware.” Proceedings of Graphics Hardware 2005, Eurographics/ACM SIGGRAPH, July 2005. http://www.cs.umbc.edu/~olano/papers/mNoise.pdf
  - Most use several textures for tables
  - Use 60 – 80 GPU instructions

References

Perlin, K. 1999. Making Noise. Presented at GDCHardCore. http://www.noisemachine.com/talk1/

Perlin, K. 2002. Improving noise. In *Proceedings of the 29th Annual Conference on Computer Graphics and interactive Techniques* (San Antonio, Texas, July 23 - 26, 2002). SIGGRAPH '02. ACM, New York, NY, 681-682. http://mrl.nyu.edu/~perlin/noise/

Zucker, Matt. 2001. The Perlin noise math FAQ. http://www.cs.cmu.edu/~mzucker/code/perlin-noise-math-faq.html

http://freespace.virgin.net/hugo.elias/models/m_perlin.htm

Anti-aliasing Procedural Textures

- How can we control aliasing in procedural textures?
  - No magic mipmapping for procedural textures!
- Three common solutions:
  - Supersampling – expensive!
  - Analytical anti-aliasing – difficult!
  - Render to a texture, use mipmapping – sets an upper bound on texture resolution, may consume a lot of memory

Anti-aliasing – Supersampling

- Determine the size / shape of the sample area
  - The GLSL functions `dFdx()`, `dFdy()`, and `fwidth()` provide this information
    - These are called *partial derivatives*
    - Not available in unextended OpenGL ES 2.0
      - Added by `GL_OES_standard_derivatives`
  - Roughly the same information used by the texture filtering hardware

Anti-aliasing – Supersampling

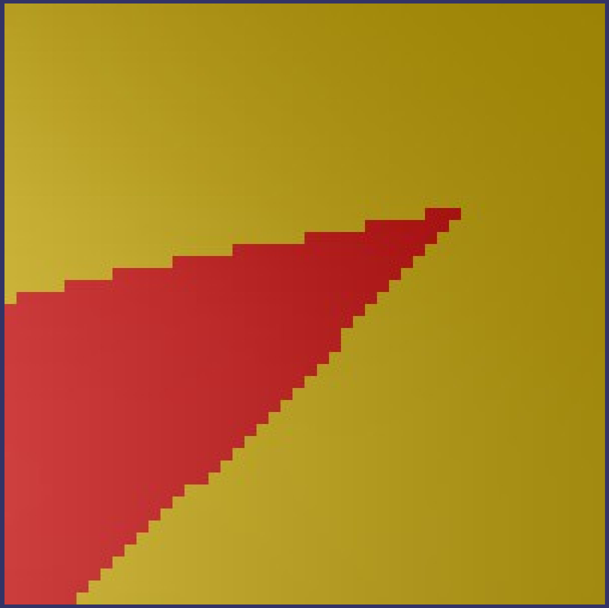
- Perform multiple texture calculations within the sample area
  - A rectangle based on `dFdx()` and `dFdy()` should be sufficient
  - Filter (average) the results

Anti-aliasing – Analytical

- Formulate the shader to calculate the average color over an area
  - Usually ranges from difficult to nearly impossible

Anti-aliasing – Index Aliasing

- Sometimes the boundary function causes aliasing
  - Remember the toy ball shader:



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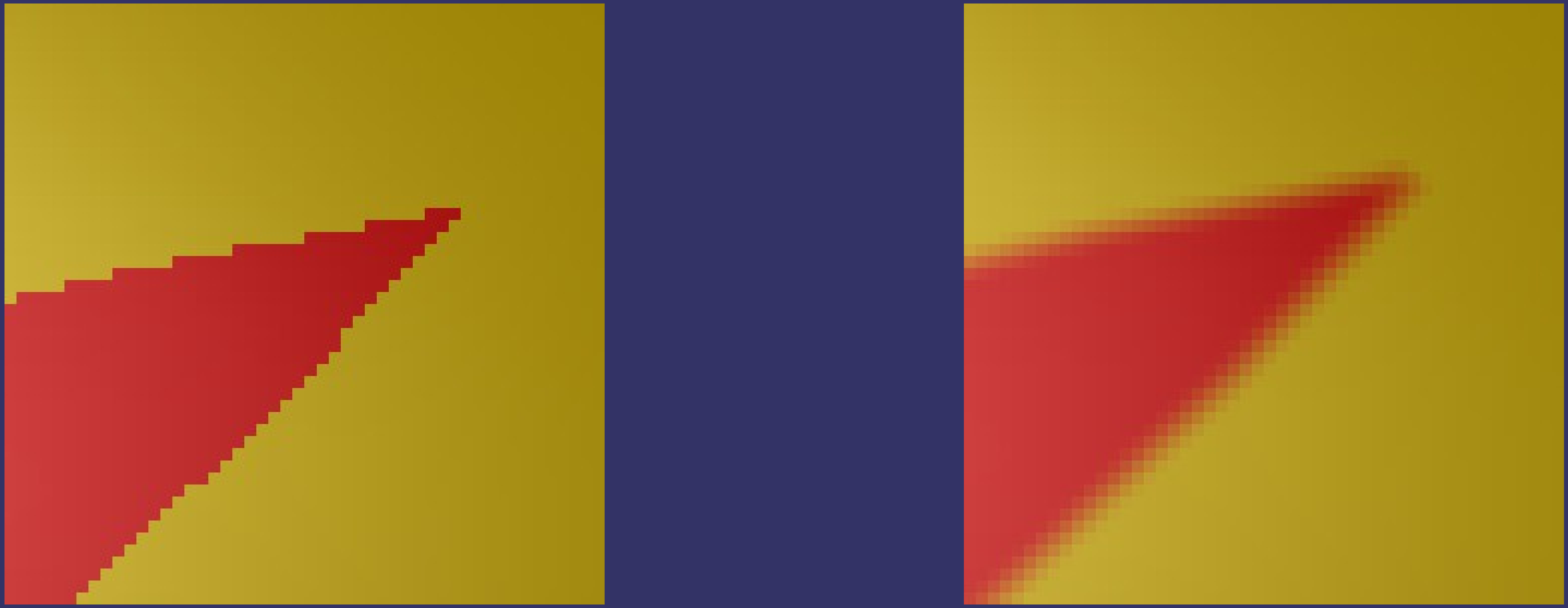
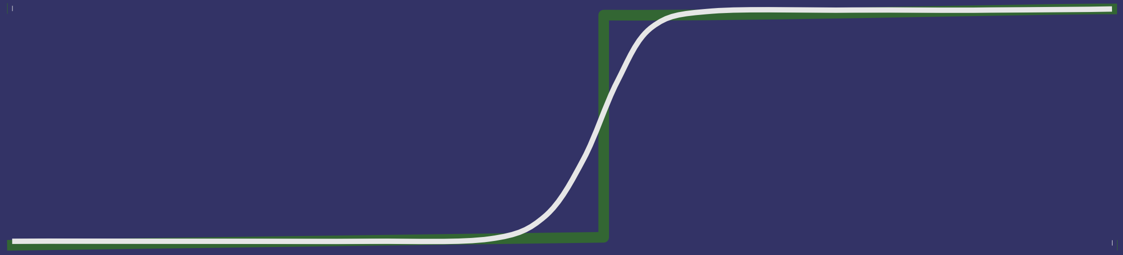


Anti-aliasing – Index Aliasing

- `step` function adds unnecessary high frequency components
  - Instead use `smoothstep` based on the width of the sample area



  - Calculates: $-2t^3 + 3t^2$, $t \in [0, 1]$

References

Ebert, D. S., Musgrave, F. K., Peachey, D., Perlin, K., and Worley, S. *Texturing and Modeling: a Procedural Approach.* 3rd Ed. Morgan Kaufmann Publishers Inc., 2002.

Next week...

- And by “next week” I mean *tomorrow*...
- Quiz #1
- Render-to-texture
- Improving the lighting model
  - Environment maps as lights
  - Fresnel reflection

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