VGP352 – Week 8

- Agenda:
  - Post-processing effects
    - Filter kernels
    - Separable filters
    - Depth of field
    - HDR

2-March-2010

Filter Kernels

- Can represent our filter operation as a sum of products over a region of pixels
  - Each pixel is multiplied by a factor
  - Resulting products are accumulated
- Commonly represented as an $n \times m$ matrix
  - This matrix is called the *filter kernel*
  - m is either 1 or is equal to n

Filter Kernels

- Uniform blur over 3x3 area:
  - Larger kernel size results in more blurriness

$$\frac{1}{9}\begin{bmatrix} 1 & 1 & 1 \\ 1 & 1 & 1 \\ 1 & 1 & 1 \end{bmatrix}$$

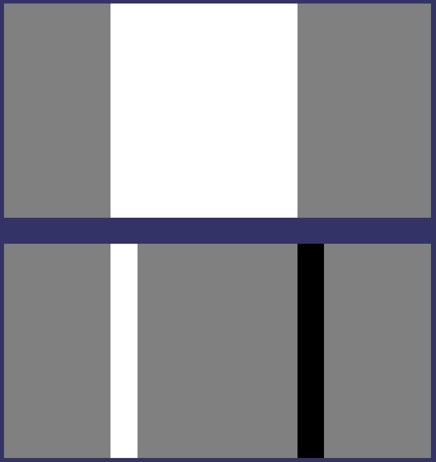
Filter Kernels – Edge Detection

- Edge detection

Filter Kernels – Edge Detection

- Edge detection
  - Take the difference of each pixel and its left neighbor

$$p(x, y) - p(x-1, y)$$



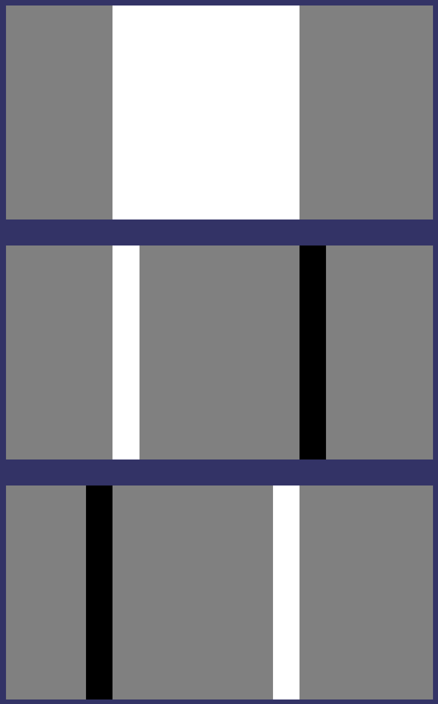
Filter Kernels – Edge Detection

- Edge detection
  - Take the difference of each pixel and its left neighbor

    $$p(x,y) - p(x-1,y)$$

  - Take the difference of each pixel and its right neighbor

    $$p(x,y) - p(x+1,y)$$



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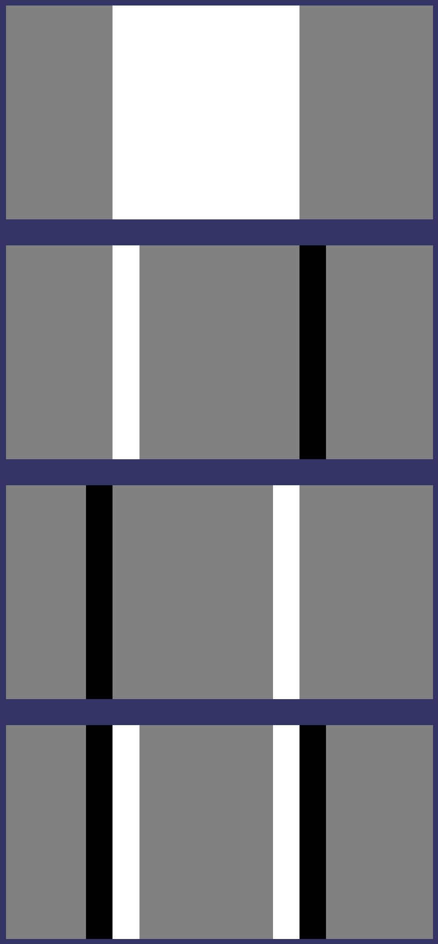
$$p(x,y)-p(x-1,y)$$

  - Take the difference of each pixel and its right neighbor

$$p(x,y)-p(x+1,y)$$

  - Add the two together

$$2p(x,y)-p(x-1,y)-p(x+1,y)$$



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- Rewrite as a kernel

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$$\begin{bmatrix} 0 & -1 & 0 \\ -1 & 4 & -1 \\ 0 & -1 & 0 \end{bmatrix}$$

- Repeat on diagonals

$$\begin{bmatrix} -1 & -1 & -1 \\ -1 & 8 & -1 \\ -1 & -1 & -1 \end{bmatrix}$$

Sobel Edge Detection

- Uses two filter kernels
  - One in the Y direction

$$F_y = \begin{bmatrix} +1 & +2 & +1 \\ 0 & 0 & 0 \\ -1 & -2 & -1 \end{bmatrix}$$

  - One in the X direction

$$F_x = \begin{bmatrix} +1 & 0 & -1 \\ +2 & 0 & -2 \\ +1 & 0 & -1 \end{bmatrix}$$

Sobel Edge Detection

- Apply each filter kernel to the image

$$G_x = F_x * A$$
$$G_y = F_y * A$$

  – G_x and G_y are the gradients in the x and y directions
  – The combined magnitude of these gradients can be used to detect edges

$$G = \sqrt{G_x^2 + G_y^2}$$

Sobel Edge Detection

Images from http://en.wikipedia.org/wiki/Sobel_operator

2-March-2010

Filter Kernels

- Implement this easily on a GPU
  - Supply filter kernel as uniforms
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Filter Kernels

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  - Supply filter kernel as uniforms
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  - Apply kernel and write result
- Perform n^2 texture reads?!?
  - n larger than 4 or 5 won't work on most hardware
  - Since the filter is a sum of products, it could be done in multiple passes
  - Or *maybe* there's a different way altogether...

Separable Filter Kernels

- Some 2D kernels can be re-written as the product of 2 1D kernels
  - These kernels are called *separable*
  - Applying each 1D kernel requires n texture reads per pixel, doing both requires $2n$
    - $2n \ll n^2$

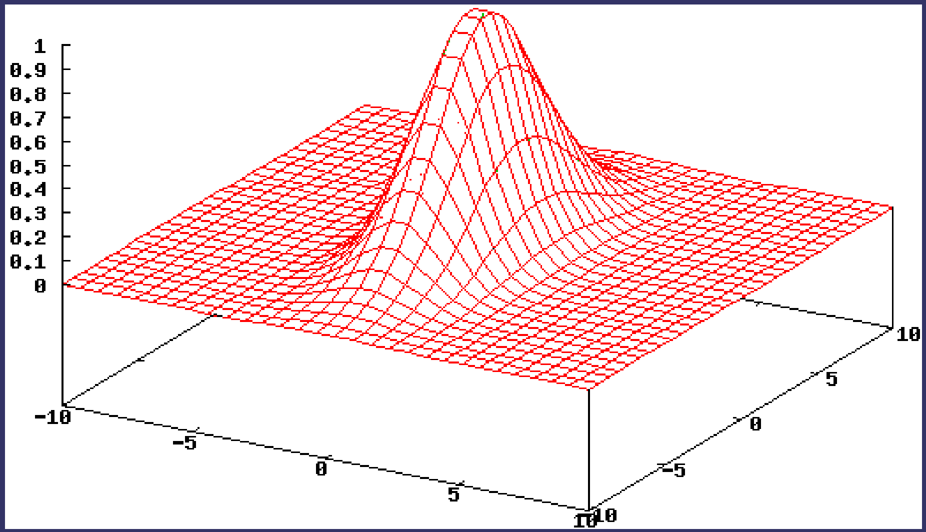
Separable Filter Kernels

- 2D kernel is calculated as the outer-product of the individual 1D kernels

$$\mathbf{A}=\mathbf{a}^{T}\mathbf{b}=\begin{bmatrix} \mathbf{a}_0\mathbf{b}_0 & \cdots & \mathbf{a}_0 b_n \\ \vdots & & \vdots \\ \mathbf{a}_n\mathbf{b}_0 & \cdots & \mathbf{a}_n\mathbf{b}_n \end{bmatrix}$$

Separable Filter Kernels

- The 2D Gaussian filter is *the classic* separable filter



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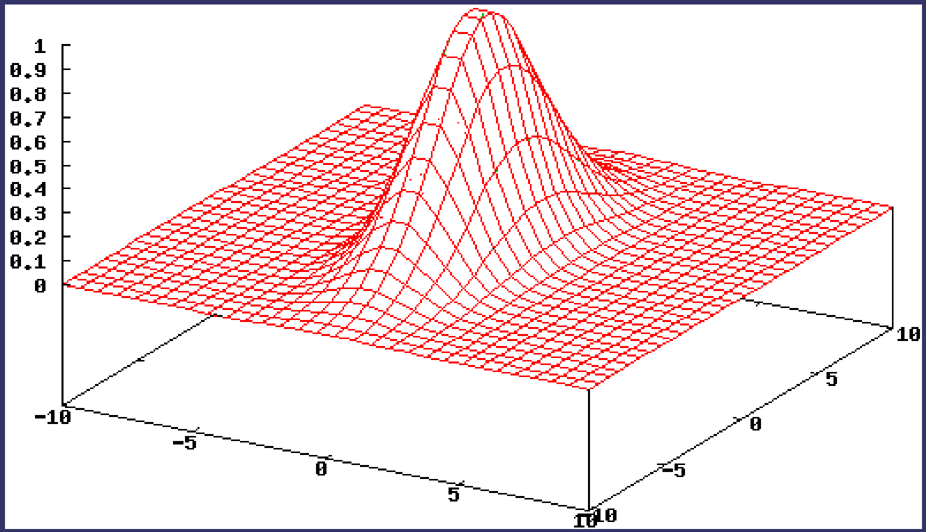
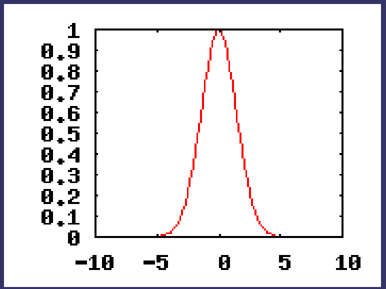


  - Product of a Gaussian along the X-axis



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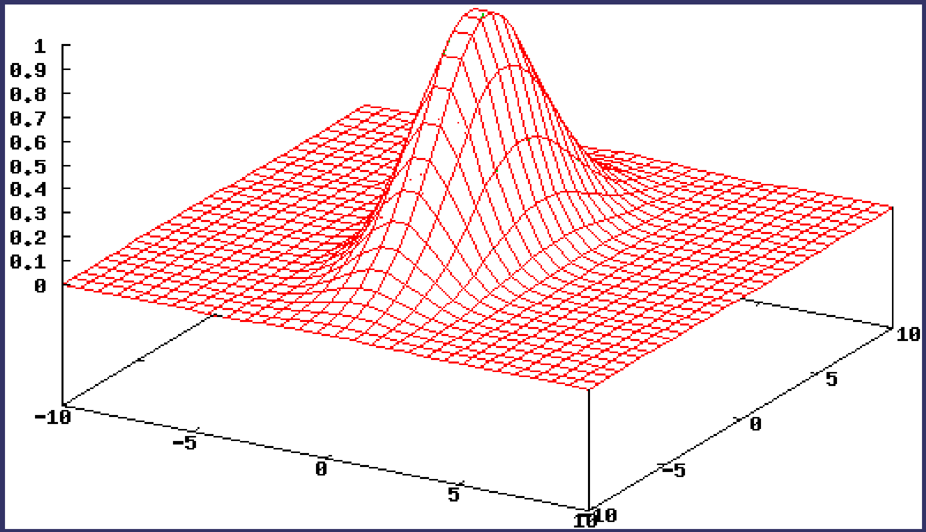

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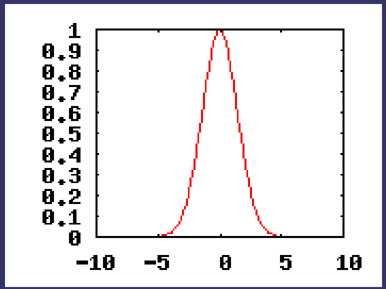
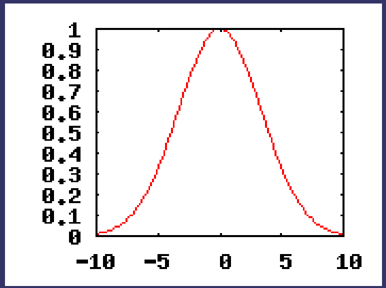


  - ...and a Gaussian along the Y-axis



Separable Filter Kernels

- Implementing on a GPU:
  - Use first 1D filter on source image *to window*
  - Configure blending for $source \times destination$

    ```
    glBlendFunc(GL_DST_COLOR, GL_ZERO);
    ```
  - Use second 1D filter on source image *to window*

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    ```
  - Use second 1D filter on source image *to window*
- Caveats:
  - Precision can be a problem in intermediate steps
  - May have to use floating-point output
  - Can also use 10-bit or 16-bit per component outputs as well
    - Choice ultimately depends on what the hardware supports

References

http://www.archive.org/details/Lectures_on_Image_Processing

Depth-of-field

- What is depth of field?
  "...the depth of field (DOF) is the portion of a scene that appears acceptably sharp in the image.[1]"

[1] http://en.wikipedia.org/wiki/Depth_of_field
Images also from http://en.wikipedia.org/wiki/Depth_of_field
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Depth-of-field

- Why is DOF important?

Images from http://en.wikipedia.org/wiki/Depth_of_field

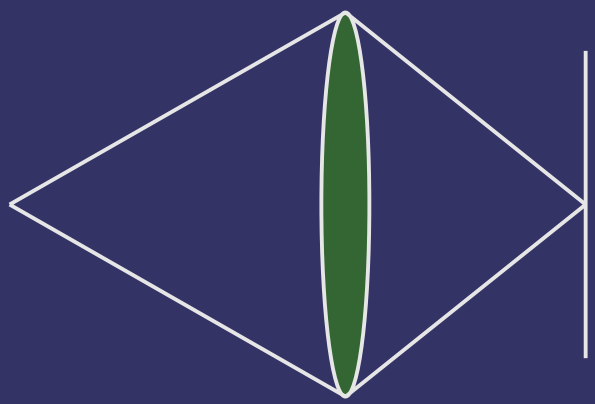
Depth-of-field

- Why is DOF important?
  - Draws viewer's attention
  - Gives added information about spatial relationships
  - etc.

Images from http://en.wikipedia.org/wiki/Depth_of_field

Depth-of-field

- Basic optics:
  - A point of light focused through a lens becomes a point on the object plane



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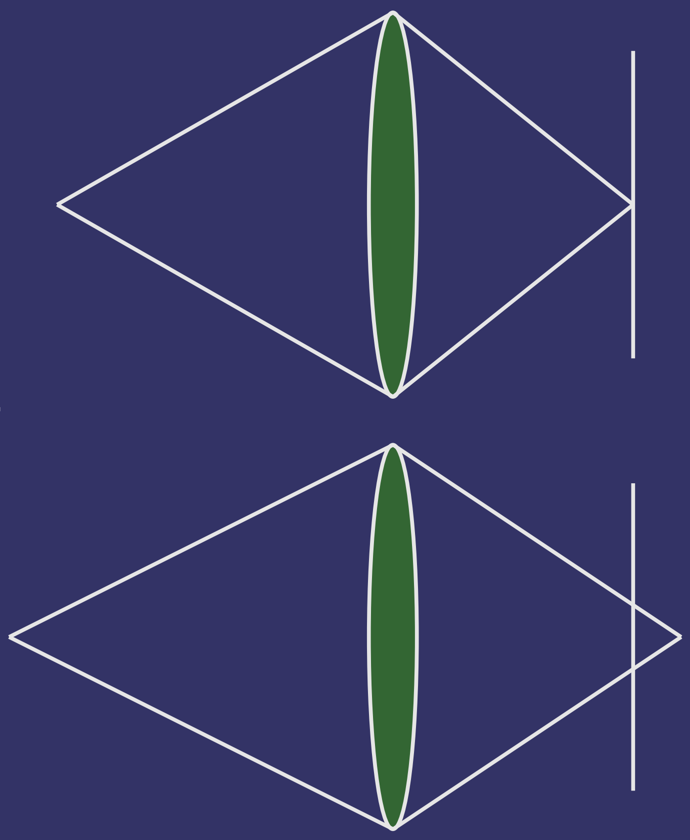
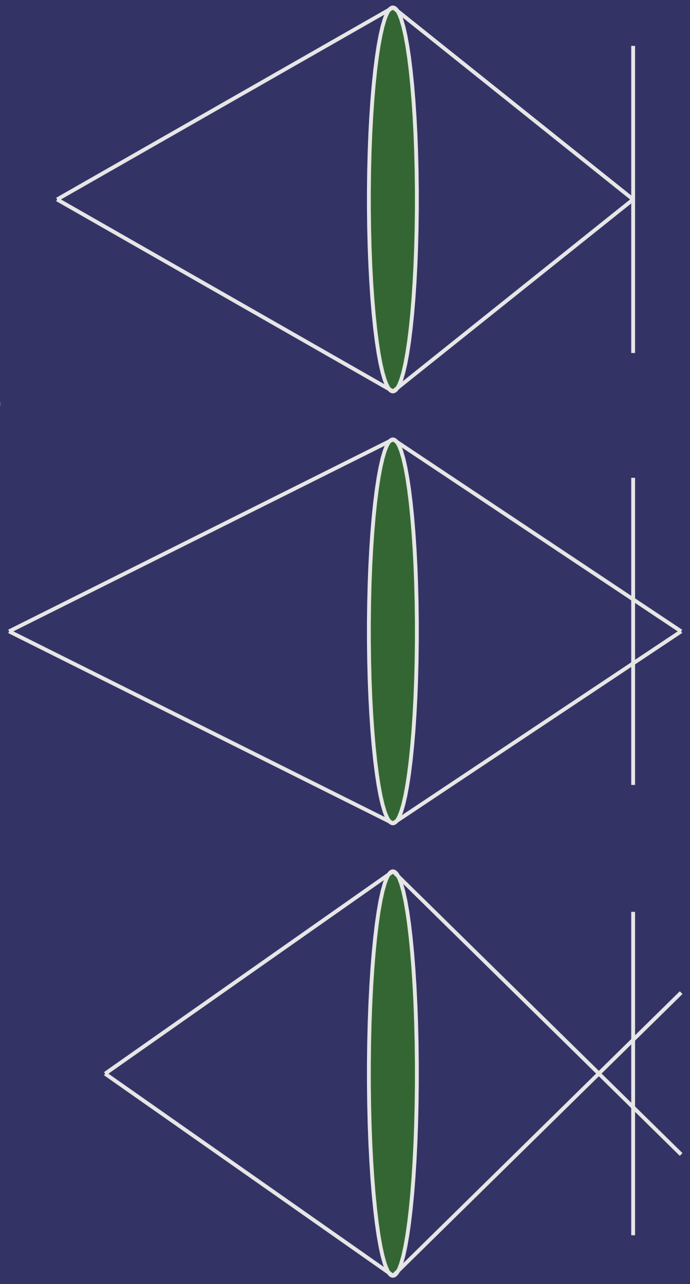


Depth-of-field

- Basic optics:
  - A point of light focused through a lens becomes a point on the object plane
  - A point farther than the focal distance becomes a blurry spot on the object plane
  - A point closer than the focal distance becomes a blurry spot on the object plane
- These blurry spots are called *circles of confusion* (CoC hereafter)



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  - Most of the time this is okay
    - The player may want to focus on foreground and background objects in rapid succession. Without eye tracking, the only way this works is to have everything in focus.
  - Under some circumstances, DOF can be a *very* powerful tool
    - Non-interactive sequences
    - Special effects
      - Very effective use in the game Borderlands

Depth-of-field

- Straight-forward GPU implementation:
  - Render scene color *and* depth information to off-screen targets
  - Post-process:
    - At each pixel determine CoC size based on depth value
    - Blur pixels within circle of confusion
      - To prevent in-focus data from bleeding into out-of-focus data, do *not* use in-focus pixels that are closer than the center pixel

Depth-of-field

- Problem with this approach?

Depth-of-field

- Problem with this approach?
  - Fixed number of samples within CoC
    - Oversample for small CoC
    - Undersample for large CoC
  - Could improve quality with multiple passes, but performance would suffer

Depth-of-field

- Simplified GPU implementation:
  - Render scene color *and* depth information to off-screen targets
  - Post-process:
    - Down-sample image and Gaussian blur down-sampled image
      - Reduced size and filter kernel size are selected to produce maximum desired CoC size
    - Linearly blend between original image and blurred image based on per-pixel CoC size

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- Problems with this approach?
  - No way to prevent in-focus data from bleeding into out-of-focus data

References

J. D. Mulder, R. van Liere. *Fast Perception-Based Depth of Field Rendering*, In *Proceedings of the ACM Symposium on Virtual Reality Software and Technology* (Seoul, Korea, October 22 - 25, 2000). VRST '00. ACM, New York, NY, 129-133. http://homepages.cwi.nl/~mullie/Work/Pubs/publications.html

Guennadi Riguer, Natalya Tatarchuk, John Isidoro. *Real-time Depth of Field Simulation*, In *ShaderX2*, Wordware Publishing, Inc., October 25, 2003. http://developer.amd.com/documentation/reading/pages/ShaderX.aspx

M. Kass, A. Lefohn, J. Owens. 2006. *Interactive Depth of Field Using Simulated Diffusion on a GPU.* Technical Memo #06-01, Pixar Animation Studios. http://graphics.pixar.com/library/DepthOfField/

High Dynamic Range

- Until now, our rendering has had a contrast ratio of 256:1
  - As noted in [Green 2004]:
    - Bright things can be really bright
    - Dark things can be really dark
    - And the details can be seen in both

High Dynamic Range

- Several possible solutions depending on hardware support / performance:
  - Render multiple “exposures” and composite results
    - This is how HDR images are captured with a camera
    - Yuck!
  - Render to floating-point buffers
    - Best quality
    - Even fp16 buffers are large / expensive
    - Differing levels of hardware support (esp. on mobile devices)
  - Render to RGBe
    - Smaller / faster
    - Lower quality
    - Issues with blending / multipass

Floating-Point Render Targets

- Create drawing surface with a floating-point internal format
  - Surface is either a texture or a renderbuffer
  - GL_RGB32F, GL_RGBA32F, GL_RGB16F, and GL_RGBA16F are most common
    - Requires GL_ARB_texture_float (and GL_ARB_half_float_pixel for 16F formats) and GL_ARB_color_buffer_float or OpenGL 3.0

Floating-Point Render Targets

- Disable [0, 1] clamping of fragments

```
glClampColorARB(GLenum target, Glenum clamp);
```

  - `target` is one of `GL_CLAMP_VERTEX_COLOR`, `GL_CLAMP_FRAGMENT_COLOR`, or `GL_CLAMP_READ_COLOR`
  - `clamp` is one of `GL_FIXED_ONLY`, `GL_TRUE`, or `GL_FALSE`
  - OpenGL 3.x version drops `ARB` from name

Floating-Point Render Targets

- Common hardware limitations:
  - May not be supported at all!
    - Almost universal on desktop, not so much on mobile
    - Intel GMA950 in most netbooks lacks support
  - May not support blending to floating-point targets
    - `RGBA32F` blending not supported on Geforce6 and similar generation chips
    - May also be *really* slow
  - May not support all texture filtering modes
    - Some hardware can't do mipmap filtering from FP textures
    - Many DX9 era cards can't do any filtering on `RGBA32F` textures

RGBe

- Store R, G, and B mantissa values with a single exponent
  - Exponent store in alpha component
  - Trades precision for huge savings on storage
    - Keeps most of the useful range of FP32

RGBe

- Convert floating-point RGB in shader to RGBe:

```
vec4 rgb_to_rgbe(vec3 color)
{
    const float max_component =
        max(color.r, max(color.g, color.b));
    const float e = ceil(log(max_component));

    return vec4(color / exp(e),
                (e + 128.0) / 255.0);
}
```

RGBe

- Limitations / problems:
  - The `log` and `exp` calls in the shader aren't free
    - May be a problem for compute bound vs. bandwidth bound shaders
  - Blending is still possible, but it is rather painful
  - Can't store components with vastly different magnitudes
    - {10000, 0.1, 0.1 } becomes {10000, 0, 0}
    - *Usually* fine for color data because the final display can't reproduce that much range anyway

Tone Mapping

- Remap HDR rendered image to LDR displayable image
  - Display still limited to [0,1] with only 8-bit precision
- Remap using Reinhard's tone reproduction operator in 5 steps:
  - Convert RGB image to luminance
  - Calculate log-average luminance
    - Used to calculate key value
  - Scale luminance by key value
  - Remap scaled luminance to [0, 1]
  - Scale RGB values by remapped luminance

Tone Mapping

- Standard luminance calculation:

$$l = \begin{bmatrix} 0.2125 & 0.7154 & 0.0721 \end{bmatrix}^T \cdot \mathbf{C}$$

  - If using RGBe, the color must be mapped back from RGBe to floating-point

Tone Mapping

- Image key:

$$k = \frac{1}{n} e^{\sum_{\text{all pixels}} \ln(\partial + l_{x,y})}$$

- Does this pixel averaging operation remind you of anything?

Tone Mapping

- Image key:

$$k = \frac{1}{n} e^{\sum_{\text{all pixels}} \ln(\partial + l_{x,y})}$$

- Does this pixel averaging operation remind you of anything?
  - It's like calculating the lowest-level mipmap!
  - ...but with some other math and emitting HDR

Tone Mapping

- Scaled luminance:

$$l_{scaled} = l_{x,y}\left(\frac{l_{mid\ zone}}{k}\right)$$

  - $l_{mid\ zone}$ is the mid zone reference reflectance value
    - 0.18 is a “common” value... see references
- Remapped luminance:

$$l_{final} = \frac{l_{scaled}}{1 + l_{scaled}}$$

- Final pass modulates l_{final} with original RGB
  - Output in plain old 8-bit RGB, naturally

Tone Mapping

- Can alternately map based on the dimmest value that should be full intensity

$$l_{final} = \frac{l_{scaled}\left(1 + \frac{l_{scaled}}{l_{min\ white}}\right)}{1 + l_{scaled}}$$

  - $l_{minwhite}$ is the minimum HDR intensity that should be mapped to fully bright

Tone Mapping

- Tone map operation is performed each frame

Tone Mapping

- Tone map operation is performed each frame
  - Ouch!
  - Common practice is to only recompute k every few frames
    - Once every half second is common
    - Has the realistic side-effect of not immediately responding to dramatic changes in scene brightness

Bloom

- Overly bright areas leak brightness into neighboring areas

Bloom

- Overly bright areas leak brightness into neighboring areas
  - Apply “bright pass” filter to image
    - Pixels above a certain threshold keep their luminance, everything else becomes black
  - Apply Gaussian blur
  - Add blurred image to final LDR image

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This step can be very expensive!

Bloom

- Blur optimization:
  - Make multiple down-scaled images (i.e., mipmaps)
    - Largest image should be 1/8th the size of the original
  - Blur each down-scaled image
    - This approximates a doubling of the filter kernel size
  - Apply small filter kernel
    - [Kalogirou 2006] suggests 5x5 is sufficient

References

Simon Green and Cem Cebenoyan (2004). "High Dynamic Range Rendering (on the GeForce 6800)." GeForce 6 Series. nVidia. http://download.nvidia.com/developer/presentations/2004/6800_Leagues/6800_Leagues_HDR.pdf

Adam Lake, Cody Northrop, and Jeff Freeman. “High Dynamic Range Environment Mapping On Mainstream Graphics Hardware.” 2005. http://www.gamedev.net/reference/articles/article2485.asp

Harry Kalogirou (2006). “How to do good bloom for HDR rendering.” http://harkal.sylphis3d.com/2006/05/20/how-to-do-good-bloom-for-hdr-rendering/

Next week...

- Beyond bumpmaps:
  - Relief textures
  - Parallax textures
  - Interior mapping

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