VGP352 – Week 10

- Agenda:
  - Texture rectangles
  - Post-processing effects
    - Filter kernels
      - Simple blur
      - Edge detection
    - Separable filter kernels
      - Gaussian blur
    - Depth-of-field

Texture Rectangle

- Cousin to 2D textures

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  - Dimensions need not be power of two
  - Texture accessed by coordinates on $[0, w\text{-}1] \times [0, h\text{-}1]$ instead of $[0, 1] \times [0, 1]$

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 viewport, projection, and modelview matrices to 1-to-1 mapping

```
glViewport(0, 0, w, h);
glMatrixMode(GL_PROJECTION);
glLoadIdentity();
glOrtho(0, w, 0, h, -1, 1);
glMatrixMode(GL_MODELVIEW);
glLoadIdentity();
```

- Draw full-screen quad with appropriate texture coordinates

```
glBegin(GL_QUADS);
glTexCoord2f(0.0, 0.0); glVertex3f(0.0, 0.0);
glTexCoord2f(1.0, 0.0); glVertex3f(1.0, 0.0);
glTexCoord2f(1.0, 1.0); glVertex3f(1.0, 1.0);
glTexCoord2f(0.0, 1.0); glVertex3f(0.0, 1.0);
glEnd();
```

Post-processing Effects

- Texture coordinate notes:
  - If a texture rectangle is used, texture coordinates will be $[0, w\text{-}1] \times [0, h\text{-}1]$ instead of $[0, 1] \times [0, 1]$
  - If neighbor texels will need to be accessed, the texel size $[1 / (w\text{-}1), 1 / (h\text{-}1)]$ must be supplied as a uniform
    - Not needed for texture rectangles! Texel size is always 1!
  - To access many neighbors, pre-calculate some in coordinates in vertex shader

```
gl_TexCoord[0] = gl_MultiTexCoord0;
gl_TexCoord[1] = gl_MultiTexCoord0
                 + vec4(ts.x, 0.0, 0.0, 0.0);
gl_TexCoord[2] = gl_MultiTexCoord0
                 + vec4(0.0, ts.y, 0.0, 0.0);
gl_TexCoord[3] = ...
```

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

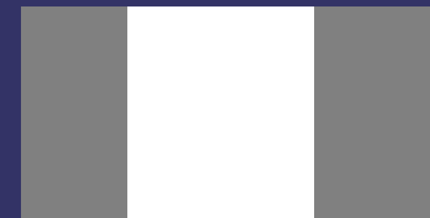
Filter Kernels

- 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

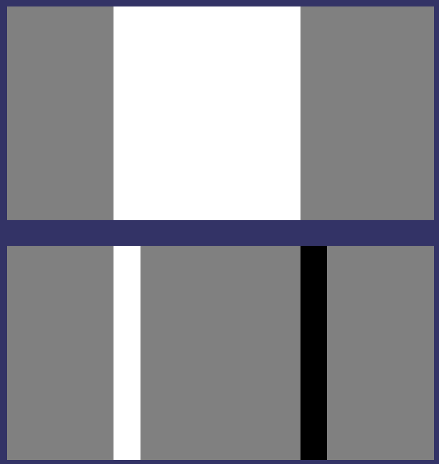
- Edge detection



Filter Kernels

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

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



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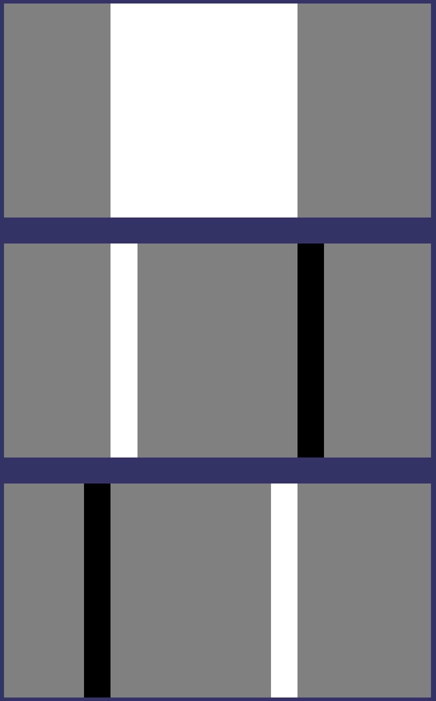

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  - Take the difference of each pixel and its left neighbor

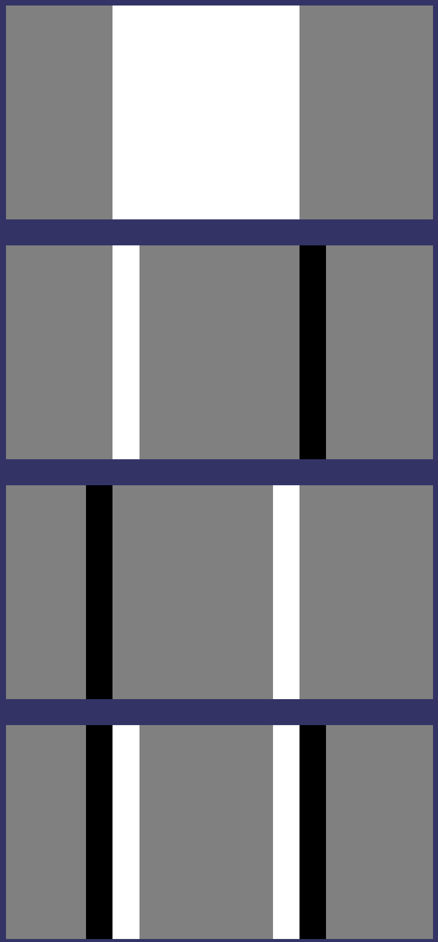
    $$p(x, y) - p(x-1, y)$$

  - Take the difference of each pixel and its left neighbor

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

  - Add the two together

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



Filter Kernels

- Rewrite as a kernel

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

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- Repeat in Y direction

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- Repeat in Y direction

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

- Repeat on diagonals

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

Filter Kernels

- Implement this easily on a GPU
  - Supply filter kernel as uniforms
  - Perform n^2 texture reads
  - Apply kernel and write result

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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 $2n$
    - $2n \ll n^2$

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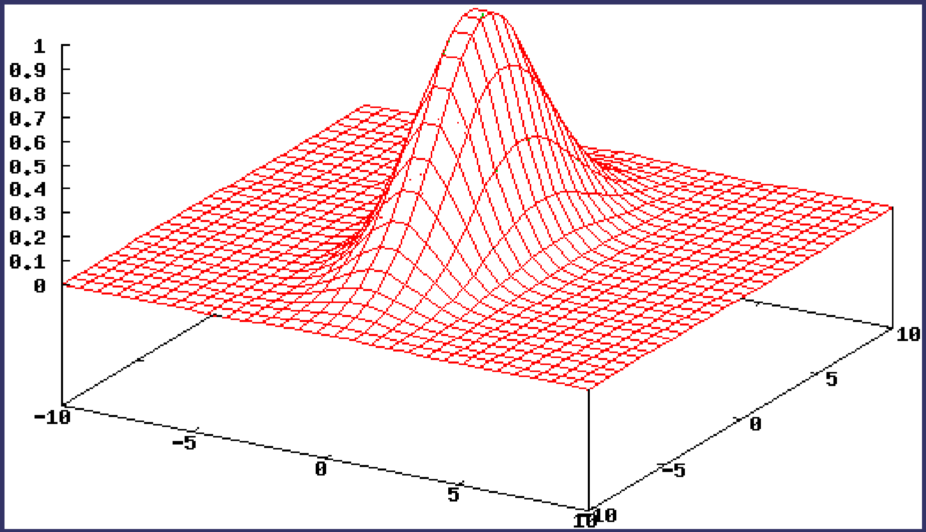
  - Applying each 1D kernel requires n texture reads per pixel, doing both requires $2n$
    - $2n \ll n^2$
- 2D kernel is calculated as the product of the 1D kernels

$$k(x, y) = k_x(x) \times k_y(y)$$

Separable Filter Kernels

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



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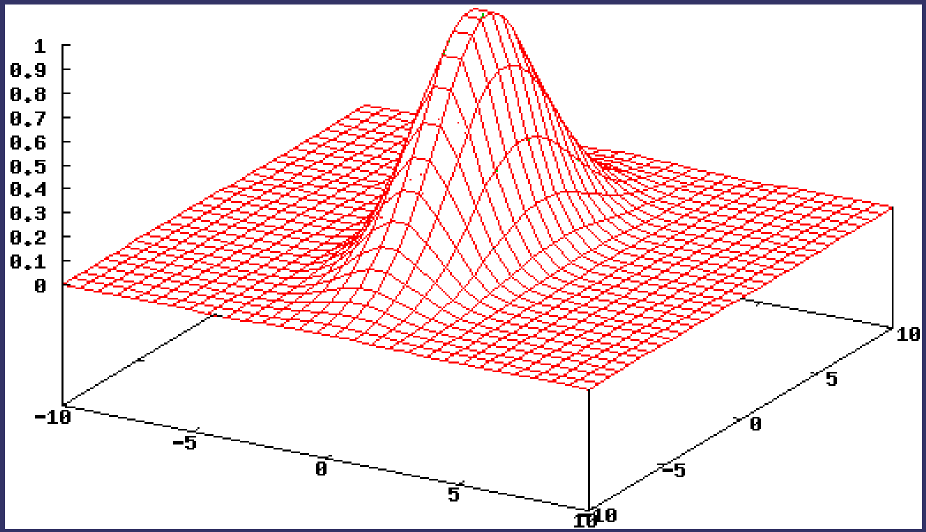
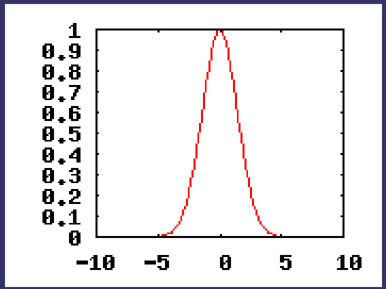


  - Product of a Gaussian along the X-axis



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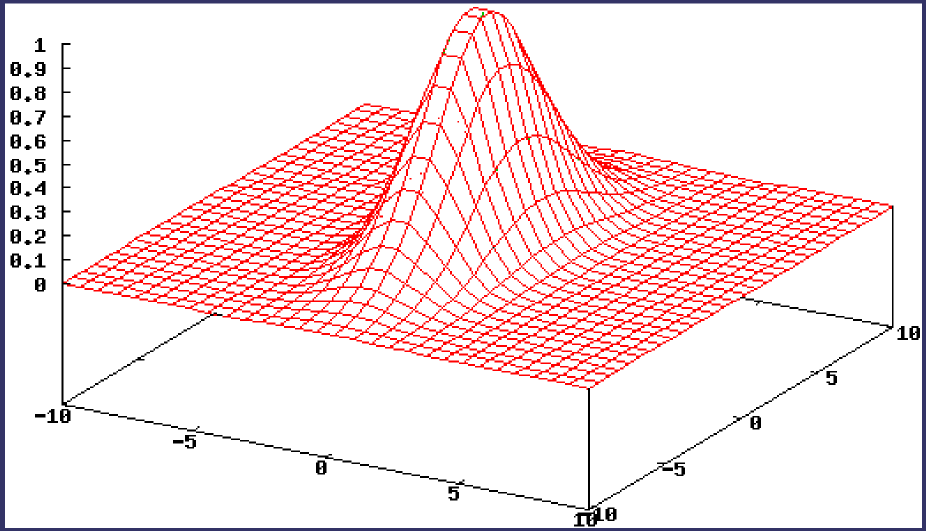

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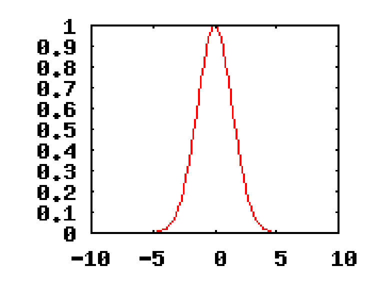
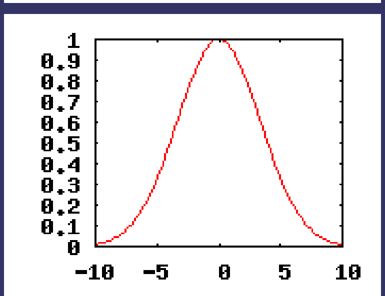


  – ...and a Gaussian along the Y-axis



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

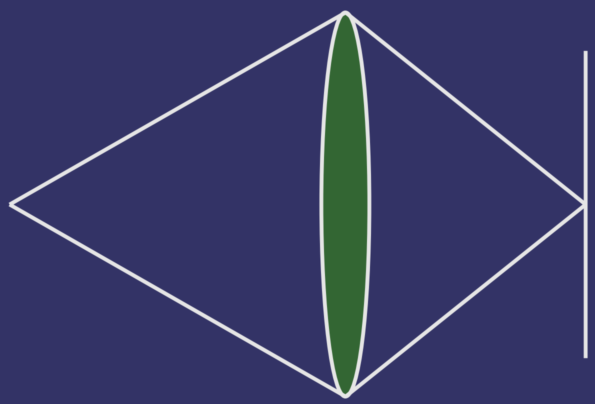
References

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

Break

Depth-of-field

- A point of light focused through a lens becomes a point on object plane



11-March-2008

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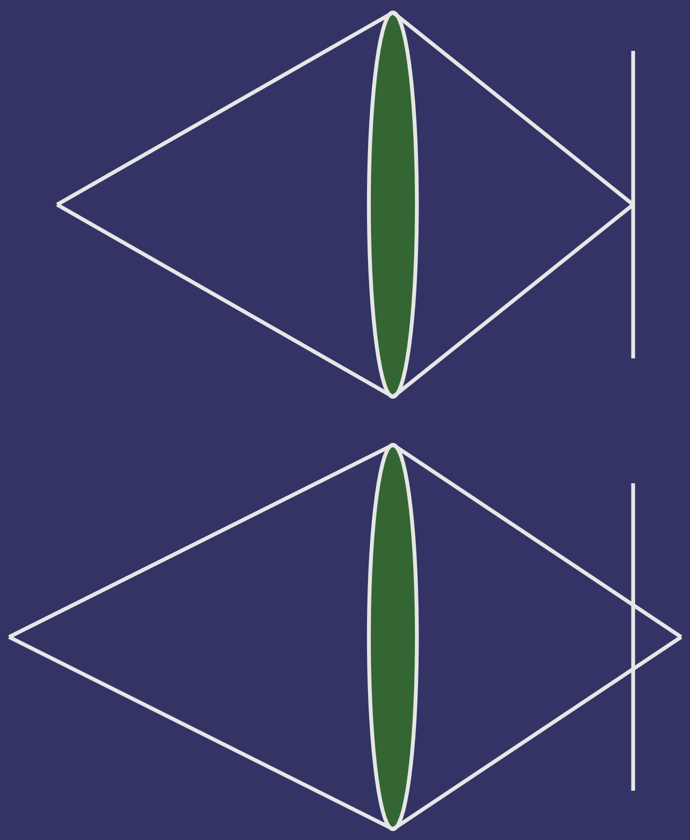
- A point of light focused through a lens becomes a point on object plane
- A point farther than the focal distance becomes a blurry spot on the object plane



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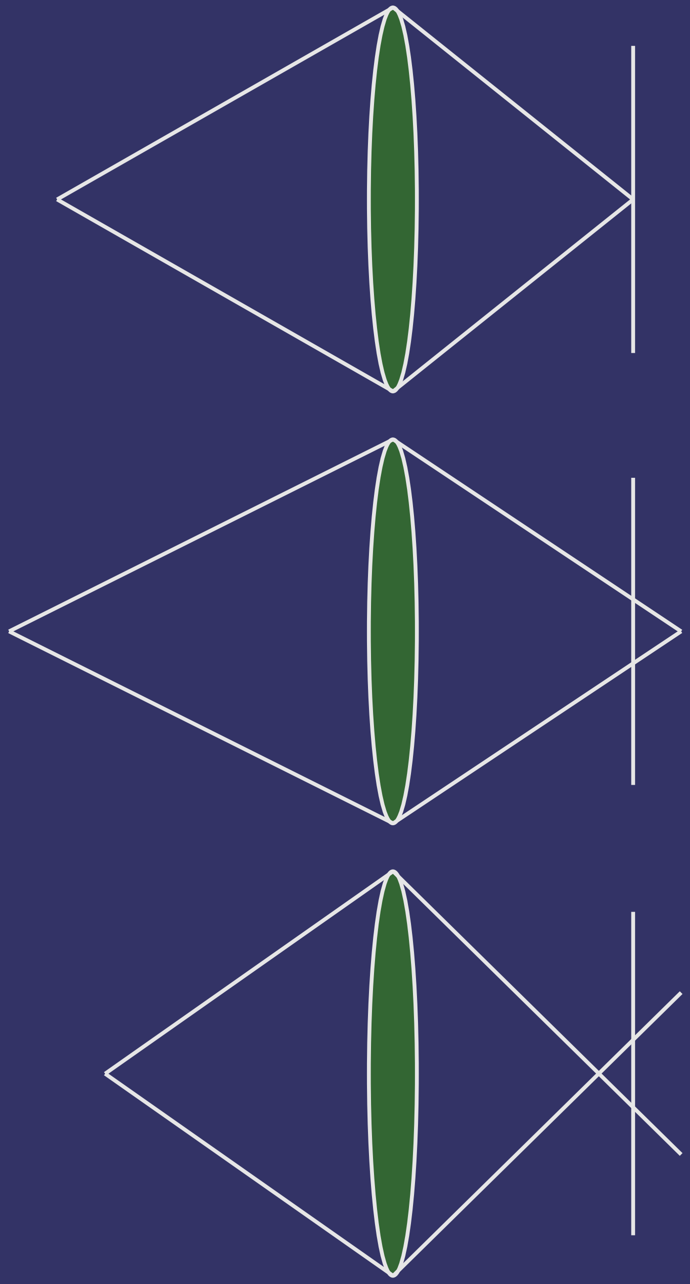

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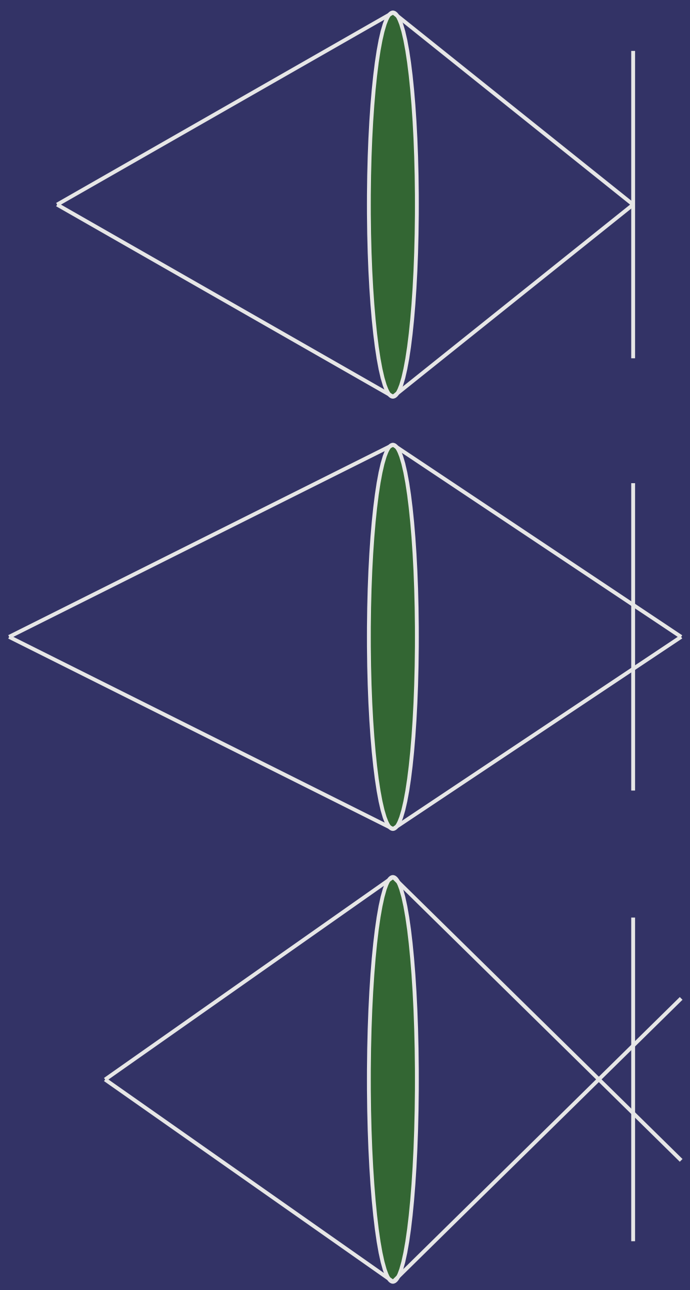
- A point of light focused through a lens becomes a point on object plane
- A point farther than the focal distance becomes a blurry spot on the object plane
- A point closer than the focal distance becomes a blurry spot on the object plane
- These blurry spots are called *circles of confusion* (CoC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



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    - In a game, the player may want to focus on foreground and background objects in rapid succession. Until we can track where the player is looking on the screen, the only way this works is to have everything in focus.
  - For non-interactive sequences, DoF can be a *very* powerful tool!
    - Film makers use this all the time to draw the audience's attention to certain things
    - Note the use of DoF in *Citizen Kane*

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

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- 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

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    - Down-sample image and Gaussian blur down-sampled image
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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

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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/DepthOfField/

Next week...

- Projects due at the start of class
- Oh yeah...the final!

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