Welcome!
Today’s Agenda:

- The Postprocessing Pipeline
  - Vignetting, Chromatic Aberration
  - Film Grain
  - HDR effects
  - Color Grading
  - Depth of Field

- Screen Space Algorithms
  - Ambient Occlusion
  - Screen Space Reflections
# Diffuse Reflection

In computer graphics, the diffuse reflection model describes how light is scattered from a surface. In this model, the light is scattered equally in all directions, with the intensity of the light being reduced by the cosine of the angle between the incident light and the surface normal. This model is often used to simulate the way that objects reflect light in the real world.

### Math Formulation

The diffuse reflection equation can be written as:

$$ \mathbf{I} = L \cdot ( \mathbf{n} \cdot \mathbf{L} ) $$

Where:
- \( \mathbf{I} \) is the reflected light intensity.
- \( L \) is the incident light direction.
- \( \mathbf{n} \) is the surface normal.
- \( \mathbf{L} \cdot \mathbf{n} \) is the dot product of the light direction and the surface normal.

### Shader Implementation

```shadertoy
vec3 EvaluateDiffuse( vec3 L, vec3 N ) { 
    float diff = dot(L, N); 
    if (diff > 0.0) { 
        return max(0.0, vec3(diff, diff, diff)); 
    } else { 
        return vec3(0.0, 0.0, 0.0); 
    }
}
```

This function takes the light direction \( L \) and the surface normal \( N \) as inputs and returns the diffuse contribution to the reflected light intensity. If the dot product of \( L \) and \( N \) is positive, the function returns the diffuse contribution, otherwise, it returns zero.

### Example Usage

```shadertoy
vec3 light_direction = vec3(1.0, 1.0, 1.0); 
vec3 normal = vec3(0.0, 0.0, 1.0); 
vec3 diffuse_light = EvaluateDiffuse(light_direction, normal); 
```

In this example, we calculate the diffuse light contribution by evaluating the function with the light direction and the surface normal.
Post Processing

*Operations carried out on a rendered image.*

**Purposes:**

- Simulation of camera effects
- Simulation of the effects of HDR
- Artistic tweaking of look and feel, separate from actual rendering
- Calculating light transport in open space
- Anti-aliasing

Post processing is handled by the *post processing pipeline.*

**Input:** rendered image, in *linear color format*

**Output:** image ready to be displayed on the monitor.
Camera Effects

Purpose: simulating camera / sensor behavior

Bright lights:

- Lens flares
- Glow
- Exposure adjustment
- Trailing / ghosting
Camera Effects

Purpose: simulating camera / sensor behavior

Camera imperfections:

- Vignetting
- Chromatic aberration
- Noise / grain
Lens Flares

Lens flares are the result of reflections in the camera lens system.

Lens flares are typically implemented by drawing sprites, along a line through the center of the screen, with translucency relative to the brightness of the light source.

Notice that this type of lens flare is specific to cameras; the human eye has a drastically different response to bright lights.
Lens Flares

“Physically-Based Real-Time Lens Flare Rendering”, Hullin et al., 2011
Camera Effects

Lens Flares

From: www.alienscribbleinteractive.com/Tutorials/lens_flare_tutorial.html
Camera Effects

Vignetting

Cheap cameras often suffer from vignetting: reduced brightness of the image for pixels further away from the center.
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Camera Effects

Vignetting

Cheap cameras often suffer from vignetting: reduced brightness of the image for pixels further away from the center.

In a renderer, subtle vignetting can add to the mood of a scene.

Vignetting is simple to implement: just darken the output based on the distance to the center of the screen.
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Camera Effects

Chromatic Aberration

This is another effect known from cheap cameras.

A camera may have problems keeping colors for a pixel together, especially near the edges of the image.

In this screenshot (from “Colonial Marines”, a CryEngine game), the effect is used to suggest player damage.
Camera Effects

Chromatic Aberration

Calculating chromatic aberration:

Use a slightly different distance from the center of the screen when reading red, green and blue.
Camera Effects

Noise / Grain

Adding (on purpose) some noise to the rendered image can further emphasize the illusion of watching a movie.

```
Noise / Grain

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```
Camera Effects

Noise / Grain

Adding (on purpose) some noise to the rendered image can further emphasize the illusion of watching a movie.

Film grain is generally not static and changes every frame. A random number generator lets you easily add this effect (keep it subtle!).

When done right, some noise reduces the ‘cleanness’ of a rendered image.
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A monitor generally does not directly display HDR images. To suggest brightness, we use hints that our eyes interpret as the result of bright lights:

- Flares
- Glow
- Exposure control
A monitor generally does not directly display HDR images. To suggest brightness, we use hints that our eyes interpret as the result of bright lights:

- Flares
- Glow
- Exposure control
HDR

HDR Bloom

Calculation of HDR bloom:

1. For each pixel, subtract (1,1,1) and clamp to 0 (this yields an image with only the bright pixels)
2. Apply a Gaussian blur to this buffer
3. Add the result to the original frame buffer.
Exposure Control / Tone Mapping

Our eyes adjust light sensitivity based on the brightness of a scene.

Exposure control simulates this effect:

1. Estimate brightness of the scene;
2. Gradually adjust ‘exposure’;
3. Adjust colors based on exposure.

Exposure control happens before the calculation of HDR bloom.
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**Color Grading**

**Color Correction**

Changing the color scheme of a scene can dramatically affect the mood.

(in the following movie, notice how often the result ends up emphasizing blue and orange)*

Color Grading

Color Correction

Color correction in a real-time engine:

1. Take a screenshot from within your game
2. Add a color cube to the image
3. Load the image in Photoshop
4. Apply color correction until desired result is achieved
5. Extract modified color cube
6. Use modified color cube to lookup colors at runtime.
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Gamma Correction

Concept

Monitors respond in a non-linear fashion to input.
Gamma Correction

Concept

Monitors respond in a non-linear fashion to input:

Displayed intensity \( I = a^\gamma \)

Example for \( \gamma = 2 \):

\[
\begin{align*}
a &= \left\{ 0, \frac{1}{4}, \frac{1}{2}, \frac{3}{4}, 1 \right\} & \rightarrow & & I = \left\{ 0, \frac{1}{16}, \frac{1}{4}, \frac{9}{16}, 1 \right\}
\end{align*}
\]

Let's see what \( \gamma \) is on the beamer.

*On most monitors, \( \gamma \approx 2 \).*
How to deal with $\gamma \approx 2$

First of all: we will want to do our rendering calculations in a linear fashion.

Assuming that we did this, we will want an intensity of 50% to show up as 50% brightness.

Knowing that $I = a^\gamma$, we adjust the input: $a' = a^{\frac{1}{\gamma}}$ (for $\gamma=2$, $a' = \sqrt{a}$), so that $I = a'^\gamma = (a^{\frac{1}{\gamma}})^\gamma = a$. 
Gamma Correction

How to deal with $\gamma \approx 2$

Apart from ‘gamma correcting’ our output, we also need to pay attention to our input.

This photo looks as good as it does because it was adjusted for screens with $\gamma \approx 2$.

In other words: the intensities stored in this image file have been processed so that $a'\gamma$ yields the intended intensity; i.e. linear values $a$ have been adjusted:  

$$a' = a'\gamma.$$  

We restore the linear values for the image as follows:  

$$a = a'\gamma.$$
Gamma Correction

Linear workflow

To ensure correct (linear) operations:

1. Input data \( a' \) is linearized: \( a = a'^\gamma \)
2. All calculations assume linear data
3. Final result is gamma corrected: \( a' = \frac{1}{\gamma} \)
4. The monitor applies a non-linear scale to obtain the final linear result \( a \).

Interesting fact: modern monitors have no problem at all displaying linear intensity curves: they are forced to use a non-linear curve because of legacy...
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A pinhole camera maps incoming directions to pixels.

Pinhole: aperture size = 0

For aperture sizes > 0, the lens has a focal distance.

Objects not precisely at that distance cause incoming light to be spread out over an area, rather than a point on the film.

This area is called the ‘circle of confusion’.
Depth of Field in a Ray Tracer

To model depth of field in a ray tracer, we exchange the pinhole camera (i.e., a single origin for all primary rays) with a disc.

Notice that the virtual screen plane, that we used to aim our rays at, is now the focal plane. We can shift the focal plane by moving (and scaling!) the virtual plane.

We generate primary rays, using Monte-Carlo, on the 'lens'.
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We generate primary rays, using Monte-Carlo, on the 'lens'.

The red dot is now detected by two pixels.
Depth of Field in a Rasterizer

Depth of field in a rasterizer can be achieved in several ways:

1. Render the scene from several viewpoints, and average the results;
2. Split the scene in layers, render layers separately, apply an appropriate blur to each layer and merge the results;
3. Replace each pixel by a disc sprite, and draw this sprite with a size matching the circle of confusion;
4. Filter the ‘in-focus’ image to several buffers, and blur each buffer with a different kernel size. Then, for each pixel select the appropriate blurred buffer.
5. As a variant on 4, just blend between a single blurred buffer and the original one.

Note that in all cases (except 1), the input is still an image generated by a pinhole camera.
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WAVE 1
TAKE DOWN ALL HOSTILES
HOSTILES REMAINING
5
Ambient Occlusion

Concept

Ambient occlusion was designed to be a scale factor for the ambient factor in the Phong shading model.

A city under a skydome: assuming uniform illumination from the dome, illumination of the buildings is proportional to the visibility of the skydome.
Ambient Occlusion

Concept

This also works for much smaller hemispheres:

- The portion of the hemisphere surface that is visible from the point;
- Or the average distance we can see before encountering an occluder.
Concept

Ambient occlusion is generally determined using Monte Carlo integration, using a set of rays.

\[ AO = \frac{1}{N} \sum_{i=1}^{N} V_{P,\bar{w}}(\vec{N} \cdot \bar{w}) \]

or

\[ AO = \frac{1}{N} \sum_{i=1}^{N} \frac{D_{P,\bar{w}}}{D_{\text{max}}} (\vec{N} \cdot \bar{w}) \]

where \( V \) is 1 or 0, depending on the visibility of points on the hemisphere at a fixed distance.

where \( D_{P,\bar{w}} \) is the distance to the first occluder or a point on a hemisphere with radius \( D_{\text{max}} \).
Screen Space Ambient Occlusion

We can approximate ambient occlusion in screen space, i.e., without actual ray tracing.

1. Using the z-buffer and the view vector, reconstruct a view space coordinate \( P \)
2. Generate \( N \) random points \( S_{1..i} \) around \( P \)
3. Project each \( S_{1..i} \) back to 2D screen space coordinate \( S' \), and lookup \( z \) for \( S' \)
4. We can now compare \( S_z \) to \( S'_z \) to estimate occlusion for \( S \).
Ambient Occlusion

Filtering SSAO

Applying the separable Gaussian blur you implemented already is insufficient for filtering SSAO: we don’t want to blur AO values over edges.

We use a *bilateral filter* instead.

Such a filter replaces each value in an image by a weighted average of nearby pixels. Instead of using a fixed weight, the weight is computed on the fly, e.g. based on the view space distance of two points, or the dot between normals for the two pixels.
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Reflections

Screen Space Reflections

1. Based on depth, we determine the origin of the ray;
2. Based on normal, we determine the direction;
3. We step along the ray one pixel at a time:
4. Until we find a z that is closer than our ray.

The previous point is the destination.
Reflections

Screen Space Reflections

Reflections

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Post Processing Pipeline

In: rendered image, linear color space

- Ambient occlusion
- Screen space reflections
- Tone mapping
- HDR bloom / glare
- Depth of field
- Film grain / vignetting / chromatic aberration
- Color grading
- Gamma correction

Out: post-processed image, gamma corrected
Famous Last Words

Experimenting

Use the post-processing functionality in the P3 template.

New:

```javascript
class RenderTarget

Usage:

target = new RenderTarget( screen.width, screen.height );
target.Bind();
// rendering will now happen to this target
target.Unbind();
```

Now, the texture identified by `target.GetTextureID()` contains your rendered image.
Experimenting

Use the post-processing functionality in the P3 template.

New:

```
class ScreenQuad
```

Usage:

```
quad = new ScreenQuad();
quad.Render( postprocShader, target.GetTextureID() );
```

This renders a full-screen quad using any texture (here: the render target texture), using the supplied shader. Note: no transform is used.
Example shader:

```glsl
#version 330

// shader input
in vec2 P; // fragment position in screen space
in vec2 uv; // interpolated texture coordinates
uniform sampler2D pixels; // input texture (1st pass render target)

// shader output
out vec3 outputColor;

void main()
{
    // retrieve input pixel
    outputColor = texture( pixels, uv ).rgb;

    // apply dummy postprocessing effect
    float dx = P.x - 0.5, dy = P.y - 0.5;
    float distance = sqrt( dx * dx + dy * dy );
    outputColor *= sin( distance * 200.0f ) * 0.25f + 0.75f;
}
```

```
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INFOGR – Computer Graphics
Jacco Bikker & Deabrata Panja - April-July 2018

END OF lecture 14: “Post-processing”

Next lecture: “Grand Recap”