VGP353 – Week 7

- Agenda:
  - Quiz #3
  - Ambient occlusion introduction
  - Real-time calculation of AO
  - Screen-space Ambient Occlusion, part 1

Ambient Lighting

- Hack to approximate global illumination
  - Objects occluded from the light source receive light reflected from other objects
  - Not all locations receive the same amount of indirect light

Ambient Occlusion

- The occlusion at a point is calculated as:

$$A_p = \frac{1}{\pi} \int_{\Omega} V_{p,\omega} (\mathbf{n} \cdot \omega) \, d\omega$$

  - $V_{p,\omega}$ is the visibility function at p in the direction ω

$$V_{p,\omega} = \begin{cases} 0 & \text{if } p \text{ is occluded in the } \omega \text{ direction} \\ 1 & \text{otherwise} \end{cases}$$

Ambient Occlusion

- [Zhukov, et. al 2003] suggest a slightly different formulation

$$A_p = \frac{1}{\pi} \int_\Omega \rho(L(p,\omega))(\mathbf{n} \cdot \omega) \, d\omega$$

  – $L(p, \omega)$ is the distance to the nearest occluder in the ω direction
  – ρ is an arbitrary function with the following properties:

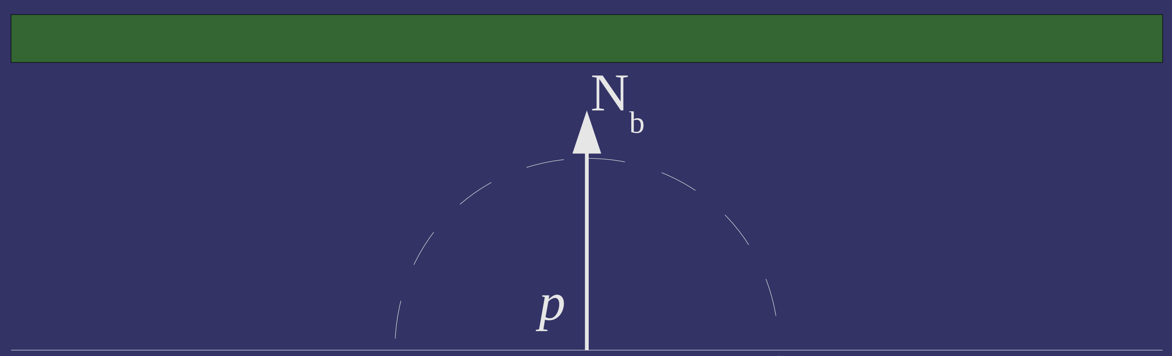
$$\rho(L) = \begin{cases} 0 & \text{for } L = 0 \\ 1 & \text{for } L = +\infty \end{cases} \quad \rho'(L) = \begin{cases} >0 & \text{for } L < +\infty \\ 0 & \text{for } L = +\infty \end{cases} \quad \rho''(L) < 0$$

    – They suggest $(1 - e^{-\tau L})$ where τ is parameter > 0

Average Light Direction Vector

- Calculate the average direction of light arriving at the point
  - Average together unoccluded rays
  - Store delta between this vector and the geometric normal along with the ambient occlusion value
  - Use this “bent normal” to access environment maps or for lighting
    - Attenuate the lighting value using the occlusion factor

Average Light Direction Vector



Average Light Direction Vector

Calculation of Ambient Occlusion

- How can we calculate A_p?

Calculation of Ambient Occlusion

- How can we calculate A_p?
  - Classic answer uses ray tracing:
    - Cast a *large number* of rays from each point on a surface.
    - Each ray that intersects some other surface within a preset distance is occluded

Calculation of Ambient Occlusion

- How can we calculate A_p?
  - Classic answer uses ray tracing:
    - Cast a *large number* of rays from each point on a surface
    - Each ray that intersects some other surface within a preset distance is occluded
  - Can also use a rasterizer:
    - Draw a low resolution hemispherical view from each point on a surface
    - Set far clip plane to limit distance
    - Pixels are either white (not drawn) or black (drawn), and the average is the occlusion value

Calculation of Ambient Occlusion

- Problems:
  - Both methods are expense
  - The expense prevents real-time update
  - Lack of real-time update prevents use on animated models

References

Ambient Occlusion. Internet, http://en.wikipedia.org/wiki/Ambient_occlusion. Accessed on August 29th, 2009.

Landis, Hayden. 2002. "Production-Ready Global Illumination." Course 16 notes, SIGGRAPH 2002. Available online at http://www.renderman.org/RMR/Books/sig02.course16.pdf.

- Chapter 5 covers ambient occlusion.
- Chapter 2 covers techniques for “texture baking.”

Iones, A., Krupkin, A., Sbert, M., and Zhukov, S. 2003. Fast, Realistic Lighting for Video Games. *IEEE Computer Graphics and Applications*. 23, 3 (May. 2003), 54–64. http://ima.udg.edu/iiia/GGG/UsersDocs/mateu/obscurances.pdf

Calculation of Ambient Occlusion

- How can we make the AO calculation faster?
  - We *really* want to use AO with animated models
  - We *really* want to use AO across the whole scene

Calculation of Ambient Occlusion

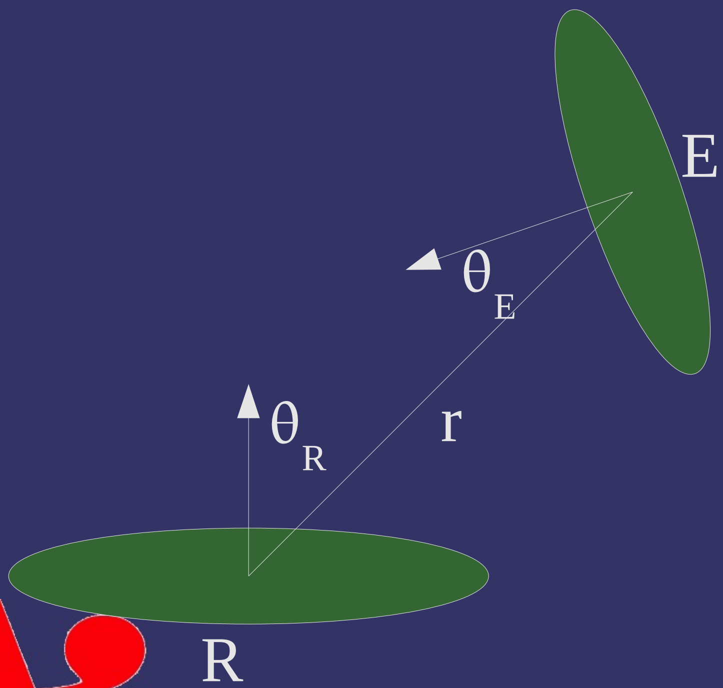
- How can we make the AO calculation faster?
  - We *really* want to use AO with animated models
  - We *really* want to use AO across the whole scene
- Three common strategies:
  - Calculate occlusion factor on GPU using GPGPU techniques (using CUDA, OpenCL, etc.)
    - See [Pharr 04]
  - Calculate approximate occlusion factor
    - See [Bunnel 05]
  - Use screen space ambient occlusion (SSAO)
    - See [Mittring 07] [Shanmugam 07]

Dynamic AO

- Approximate mesh as a set of *surface elements*
  - Each element is represented by an oriented disc
    - Each disc has a position, normal, and area
    - One disc per vertex of the original mesh
  - Disc has two sides
    - Front side emits and reflects light
    - Back side transmits light and shadows
  - Store element information in a texture

Disc-to-disc Occlusion

- Approximate the disc-to-disc occlusion
  - A is the area of the emitter



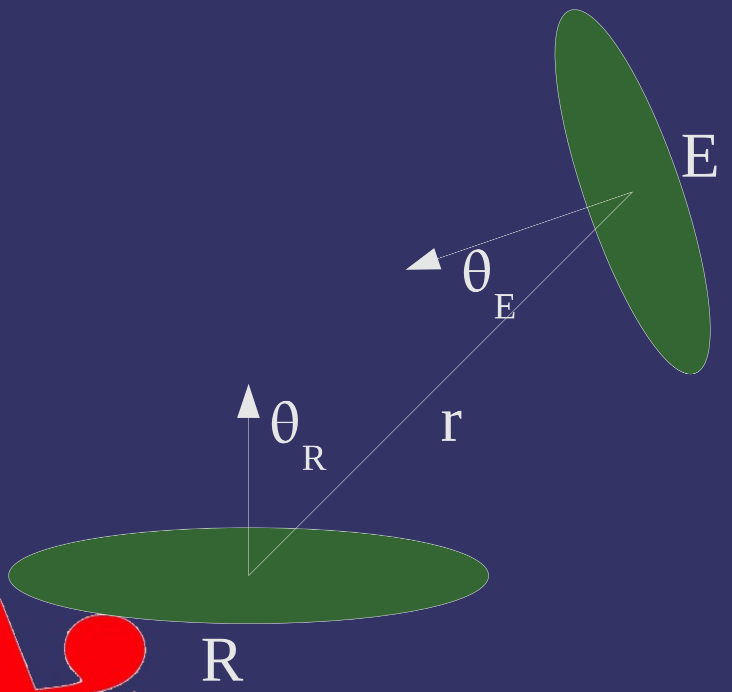
$$1-\frac{r\cos\theta_E\, max\left(1, 4\cos\theta_R\right)}{\sqrt{\frac{A}{\pi}+r^2}}$$

Disc-to-disc Occlusion

- Approximate the disc-to-disc occlusion
  - A is the area of the emitter

Disc-to-disc accessibility

$$1-\frac{r\cos\theta_E\, max\left(1, 4\cos\theta_R\right)}{\sqrt{\frac{A}{\pi}+r^2}}$$



Multipass Shadow Algorithm

- First pass:
  - Approximate accessibility for each element as one minus the sum of the accessibility to all other discs
  - After first pass, many surfaces have *too much* shadow
    - Elements that are themselves shadowed still cast shadows
- Second pass:
  - Perform same calculation as first pass
  - Multiply each form factor by the element's accessibility from the first pass
  - Some surfaces *still* have too much light
    - Elements that are triple shadowed

Multipass Shadow Algorithm

- Third pass:
  - Lather, rinse, repeat...

Multipass Shadow Algorithm

- Third pass:
  - Lather, rinse, repeat...
- Too expensive!
  - Just use a weighted average of the first two passes

Performance

- What is the time complexity of the algorithm?

Performance

- What is the time complexity of the algorithm?
  - Accessibility is computed for each of the n elements with each of the other n-1 elements
  - Sounds like $O(n^2)$

Performance

- Performs well because hardware is fast
  - Even an old Geforce 6800 can perform ~150 million calculations per second
  - Can the algorithm be improved to $O(n \log n)$?

Element Hierarchy

- Create a hierarchy of elements
  - Repeatedly merge groups of elements near each other on the mesh
- During processing, traverse the hierarchy
  - Start with the coarsest level of the hierarchy
  - If the element is far enough away, use that. Otherwise move down the hierarchy.
    - The paper suggests 4x the radius of the emitter

Indirect Lighting

- Same data structure can be used to implement a single level of indirect lighting
  - Replace the occluder function with a disc-to-disc radiance transfer function
  - Use one pass to transfer light
  - Use two passes to shadow light

Indirect Lighting

- Calculate the light reflected at each element
  - Computation proceeds as normal using either AO for environment maps or shadow maps for point lights
  - Use the disc-to-disc form factor approximation

$$\frac{A\cos\theta_E\cos\theta_R}{\pi r^2+A}$$

Indirect Lighting

- Run one pass of the radiance-transfer algorithm
  - Calculate the maximum amount of reflected (or emitted) light that can reach the element
- Run one pass of the shadow algorithm
  - Subtract from each element's total light based on how much light reaches the shadowing elements
  - Can run a third pass to remove double shadowing
    - Just like the dynamic AO algorithm

References

Pharr, Matt and Green, Simon. "Ambient Occlusion" in Fernando, Randima (editor) GPU Gems, Addison-Wesley, 2004. http://http.developer.nvidia.com/GPUGems/gpugems_ch17.html

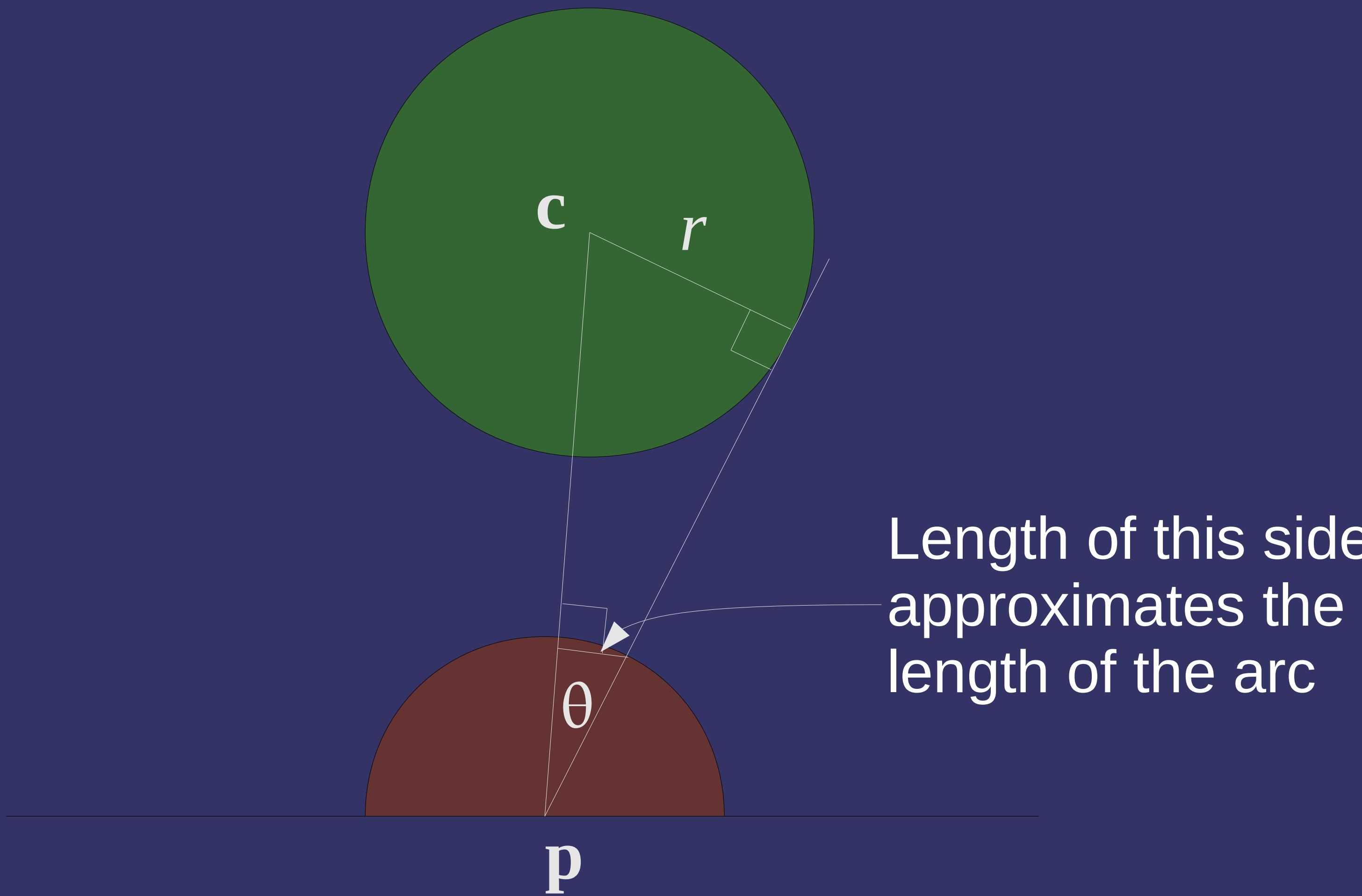
Bunnel, Michael. "Dynamic Ambient Occlusion and Indirect Lighting" in Fernando, Randima (editor) GPU Gems 2, Addison Wesley, 2005. http://download.nvidia.com/developer/GPU_Gems_2/GPU_Gems2_ch14.pdf

SSAO

- Can approximate ambient occlusion using information from the depth buffer
  - First game shipped to use this technique was Crysis by Crytek in 2007
  - The depth buffer is a rough approximation of the scene geometry

SSAO

- Approximate AO (A_Ψ) due to a sphere:



SSAO

- Approximate AO (A_Ψ) due to a sphere:

$$A_\Psi(\mathbf{c}, r, \mathbf{p}, \mathbf{n}) = S_\Omega(\mathbf{p}, \mathbf{c}, r) \max\left(\mathbf{n} \cdot \frac{\overrightarrow{\mathbf{pc}}}{|\overrightarrow{\mathbf{pc}}|}, 0 \right)$$

  - $\mathbf{c}$ and r are the center and radius of the sphere
  - $\mathbf{n}$ is the normal vector at $\mathbf{p}$
  - $\overrightarrow{\mathbf{pc}}$ is the vector from $\mathbf{p}$ to $\mathbf{c}$
  - S_Ω is surface area of the solid angle of the circle

SSAO

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$$A_\Psi(\mathbf{c}, r, \mathbf{p}, \mathbf{n}) = S_\Omega(\mathbf{p}, \mathbf{c}, r)\,\mathrm{max}\left(\mathbf{n}\cdot\frac{\overrightarrow{\mathbf{pc}}}{|\overrightarrow{\mathbf{pc}}|}, 0\right)$$

$$S_\Omega(\mathbf{p}, \mathbf{c}, r) = 2\pi h$$

$$h = 1 - \cos\theta$$

$$\theta = \sin^{-1}\left(\frac{r}{|\overrightarrow{\mathbf{pc}}|}\right)$$

$$S_\Omega(\mathbf{p}, \mathbf{c}, r) = 2\pi\left(1 - \cos\left(\sin^{-1}\left(\frac{r}{|\overrightarrow{\mathbf{pc}}|}\right)\right)\right)$$

SSAO

- Around each pixel, sample near-by positions:
  - Back project the screen (x, y, z) to camera space
    - Bias the center slightly along -**n** to prevent self-occlusion from flat surfaces
  - Back project the size of the pixel into camera space
    - This sets the size of the sphere
  - Perform approximate sphere AO calculation
- Use resulting sum to modulate color in framebuffer

SSAO

- Straightforward approach requires *piles* of samples to look good
  - The Crysis developers say ~200

SSAO

- Straightforward approach requires *piles* of samples to look good
  - The Crysis developers say ~200
- Use a similar irregular sampling technique as with PCF
  - Unlike PCF, add a geometry-aware filter
  - Rotate the kernel for each pixel
    - Repeat every N pixels
  - Results in only high-frequency noise in the final image

Geometry-Aware Filter

- Perform a normal Gaussian blur or box filter
  - Use an $N \times N$ filter size
  - Do *not* include pixels that span discontinuities
    - Use change in depth
    - Store normals in a secondary buffer and use normals
  - Eliminates most of the high-frequency noise

References

Shanmugam, P. and Arikan, O. 2007. Hardware accelerated ambient occlusion techniques on GPUs. In *Proceedings of the 2007 Symposium on interactive 3D Graphics and Games* (Seattle, Washington, April 30 - May 02, 2007). I3D '07. ACM, New York, NY, 73-80. http://perumaal.googlepages.com/

Screen Space Ambient Occlusion. Internet, http://en.wikipedia.org/wiki/Screen_Space_Ambient_Occlusion. Accessed on August 29th, 2009.

Next week...

- Bilateral filtering
- Depth peeling
- More SSAO
  - Horizon Split AO
  - Multi-Layer Dual-Resolution SSAO
- Read:

Cass Everitt, “Interactive order-independent transparency”, Technical report, NVIDIA Corporation, 2001. http://developer.nvidia.com/object/Interactive_Order_Transparency.html

Tobias Ritschel, Thorsten Grosch, Hans-Peter Seidel. Approximating Dynamic Global Illumination in Screen Space. Proceedings ACM SIGRAPH Symposium on Interactive 3D Graphics and Games, Boston, MA, February 27 —March 1, 2009. http://www.mpi-inf.mpg.de/~ritschel/SSDO/

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