CS 300: Advanced Computer Graphics I

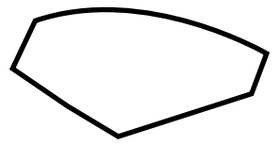
Pushpak Karnick

Lecture 23

Global Illumination & Ambient Occlusion

Introduction to Global Illumination

Illumination in Computer Graphics



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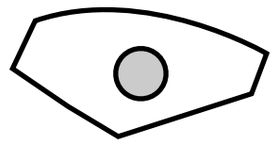

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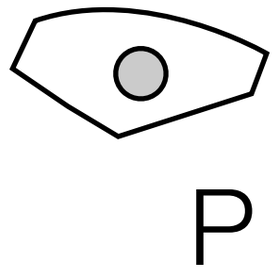

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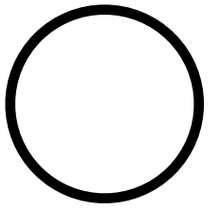

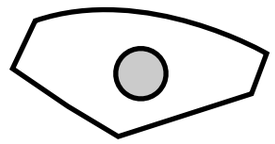

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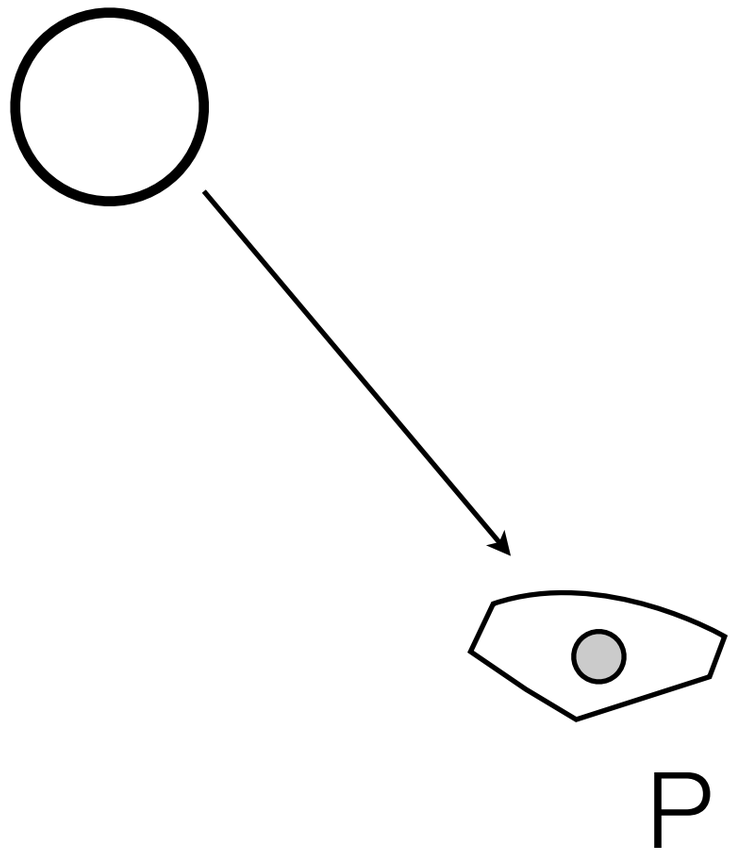

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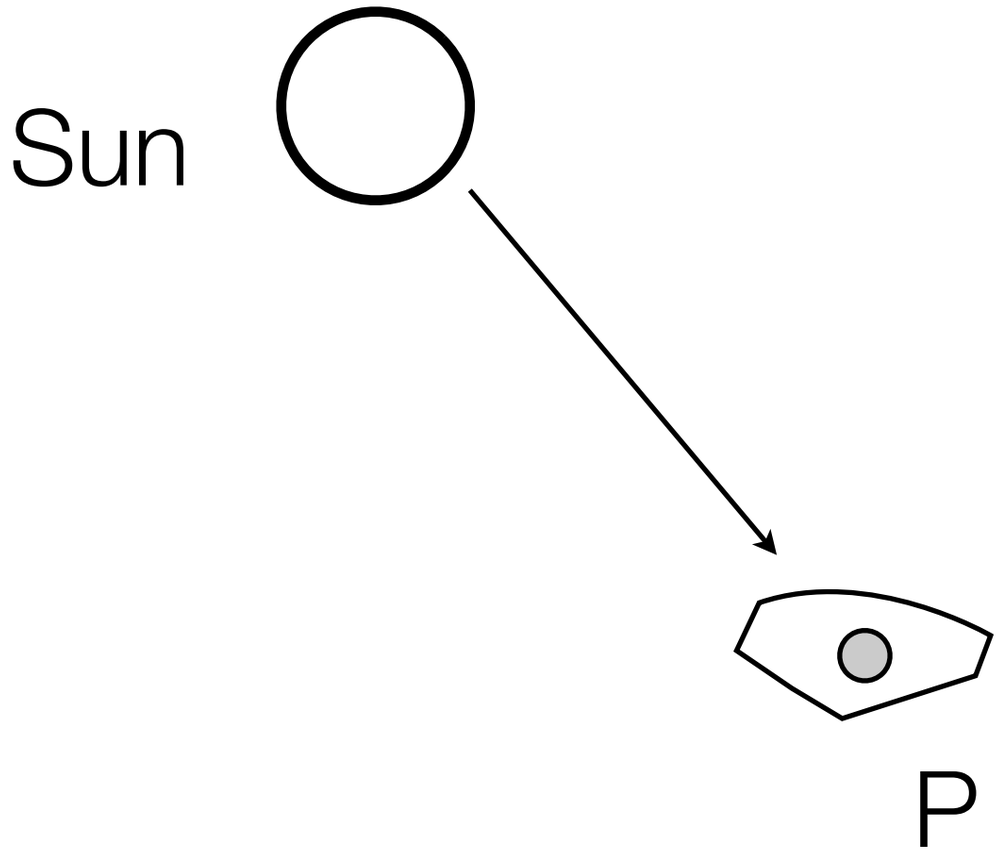

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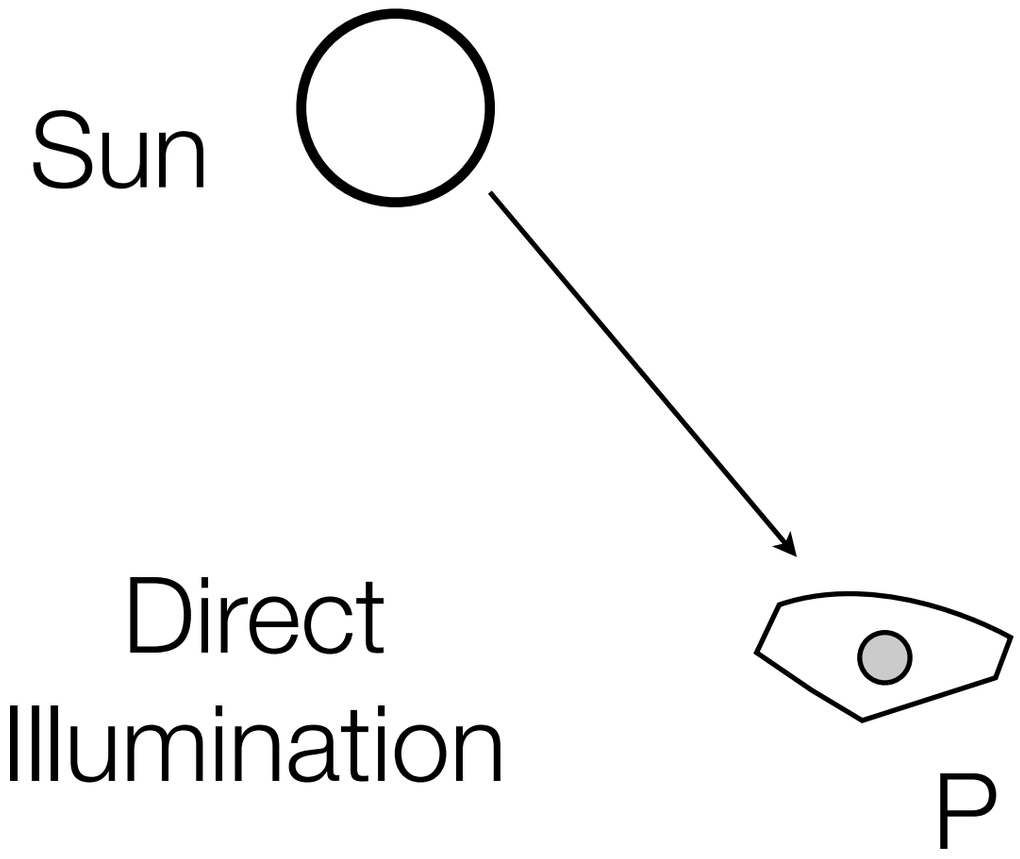

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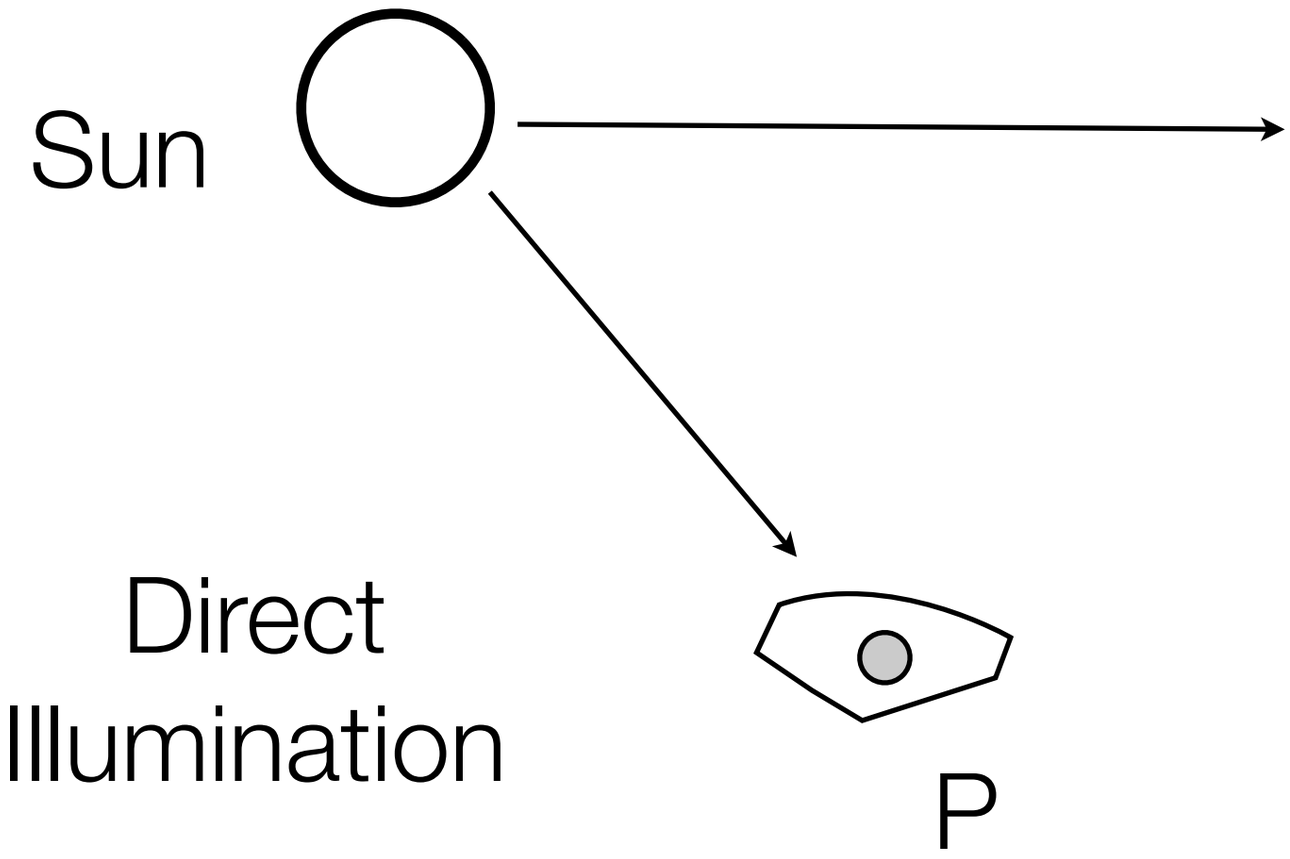

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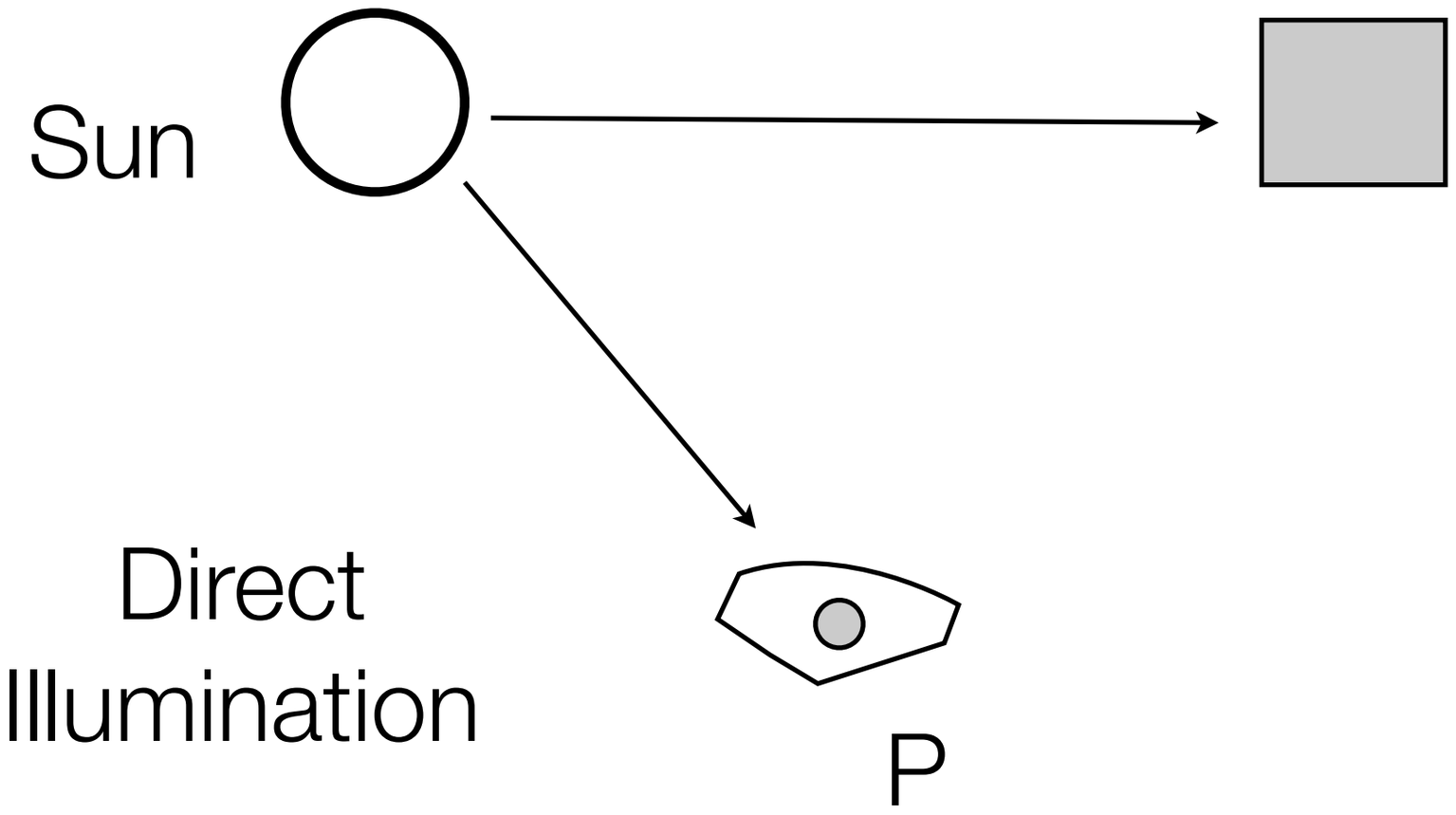

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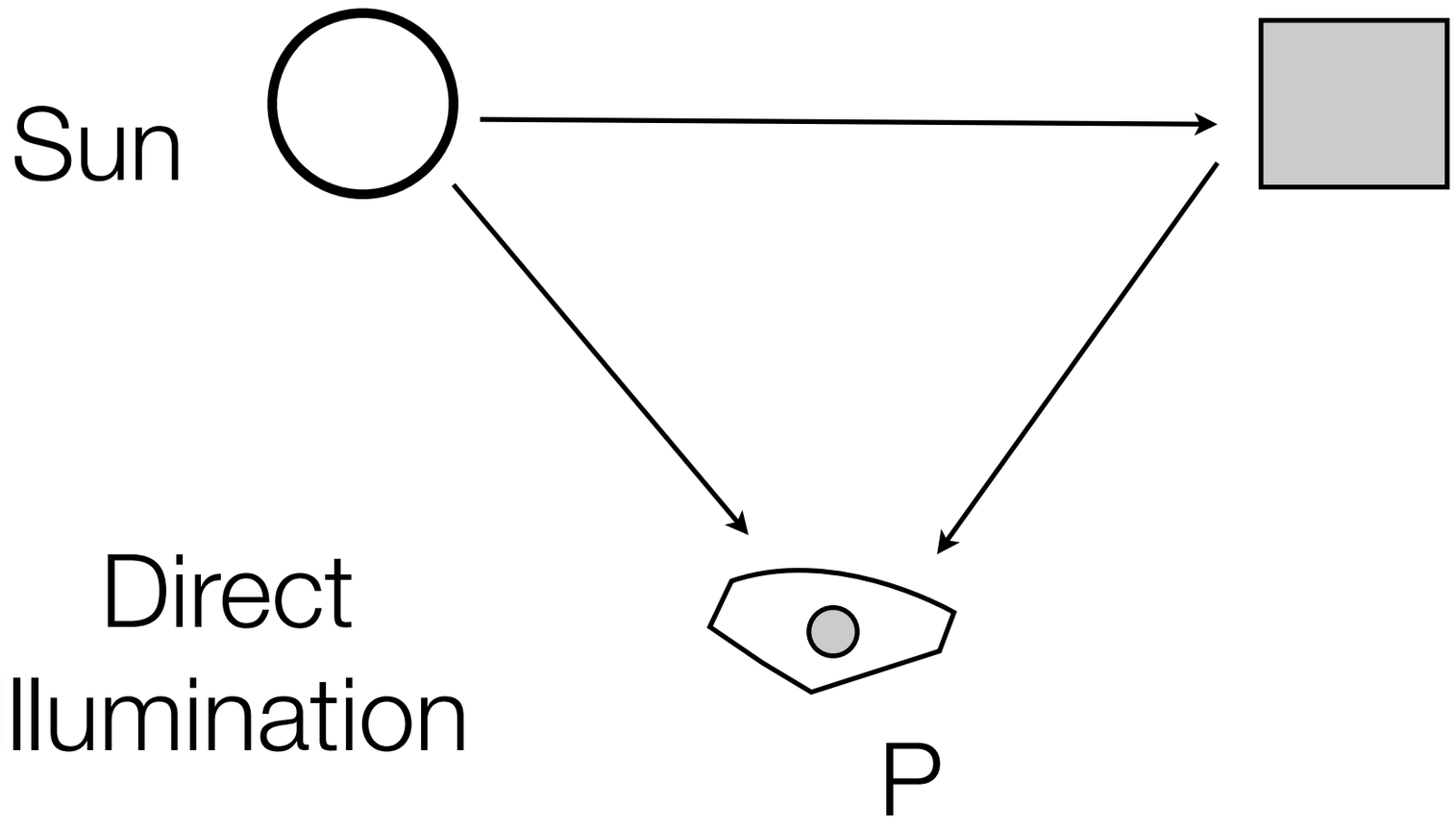

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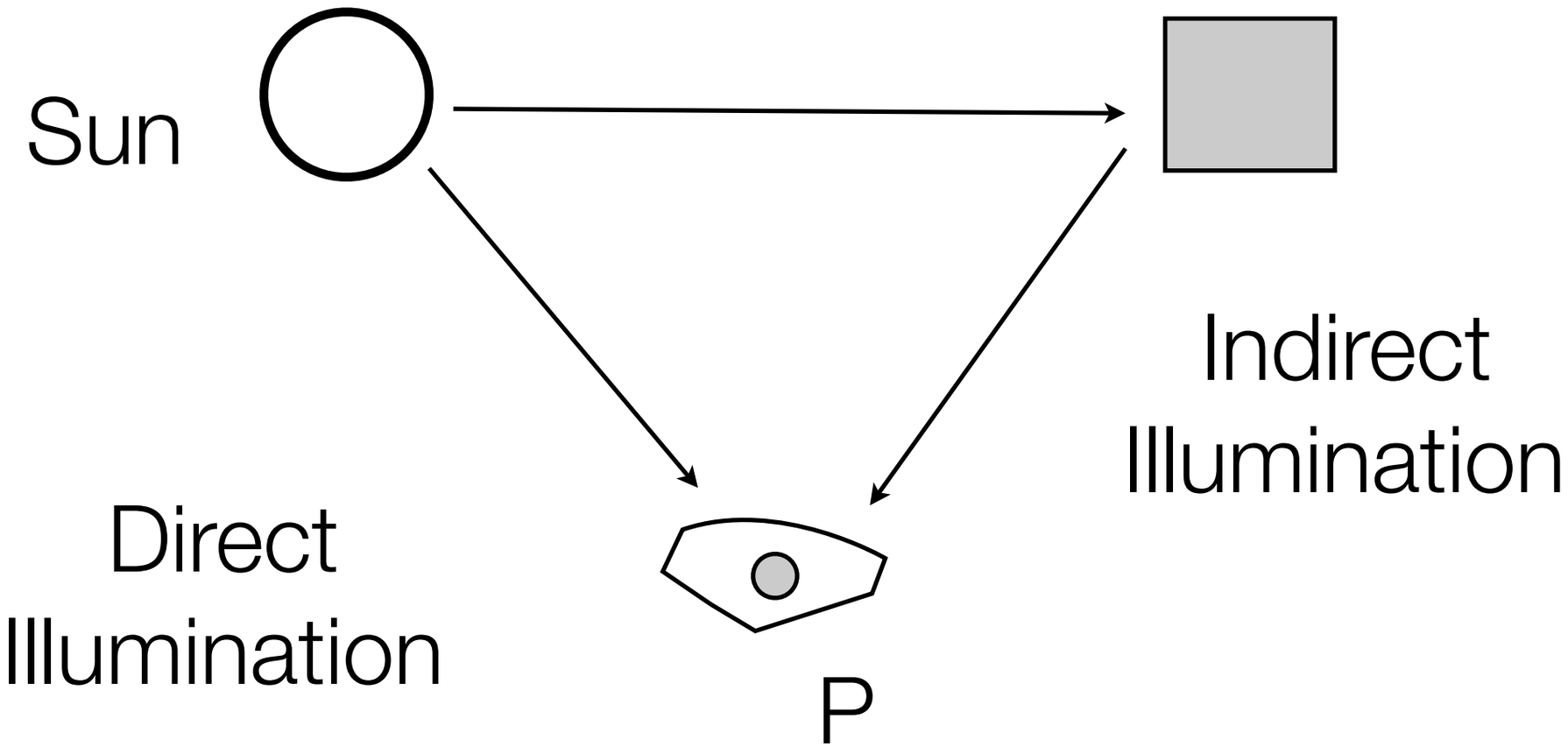

“Global” Illumination

- What is “global”?
  - The light arrives at a point from all sources
  - The light-surface interaction is “global” in nature
- **Goal:** Make the renderings as photo-realistic as possible
- **Issues:**
  - How to track light as it travels through the scene?
  - What about objects that are not self-illuminated?

Side-effects of Global Illumination

- Object-light interaction is more natural
- No special case processing for shadow generation
  - Shadows are regions where there is “not enough” incident illumination available
- Vigorous research problem in its own right

Models of Global Illumination

Mathematical Model

- Model proposed by Kajiya (1986)
  - "... to provide a unified context for viewing rendering algorithms as more or less accurate approximations to the solutions for a single equation."
- Completely general mathematical statement
- Not tied down to any particular assumption about the light transport behavior

Kajiya's Equation

$$I(x,x') = g(x,x')[\xi(x,x') + \int \rho(x,x',x'')I(x',x'')dx'']$$

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$I(x, x')$: transport intensity or the intensity of light passing from point x' to point x

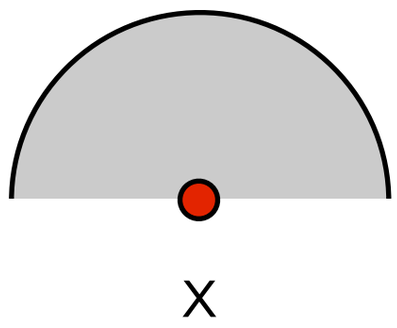
$g(x, x')$: visibility function between x and x'. If x and x' cannot 'see' each other, then this value is zero, else g varies as the square of the distance between them.

$\xi(x, x')$: the transfer emittance from x' to x related to any self-emitted light by x' towards x

$\rho(x, x', x'')$: is the scattering term wrt. direction x' and x''. It is the intensity of the energy scattered towards x from the point on surface x' arriving from point x''. Also known as the "unoccluded three-point transport reflectance."

Integral Term in Kajiya's Equation

- Integral is defined over all points on all surfaces in the scene
- Equivalently - all points surrounding point x
  - If we consider only front-faces of polygons, the region simplifies to an hemisphere around x



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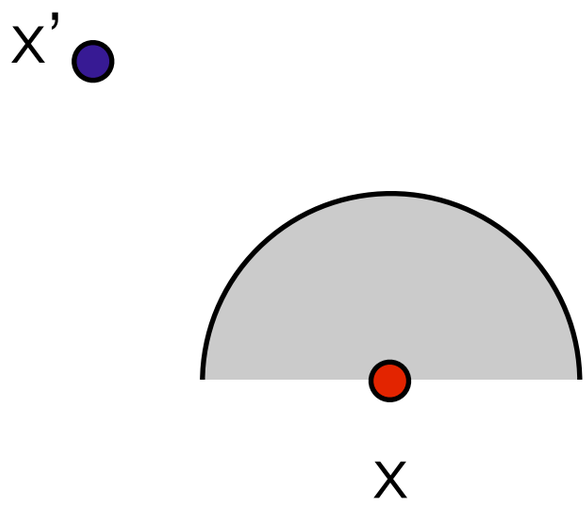

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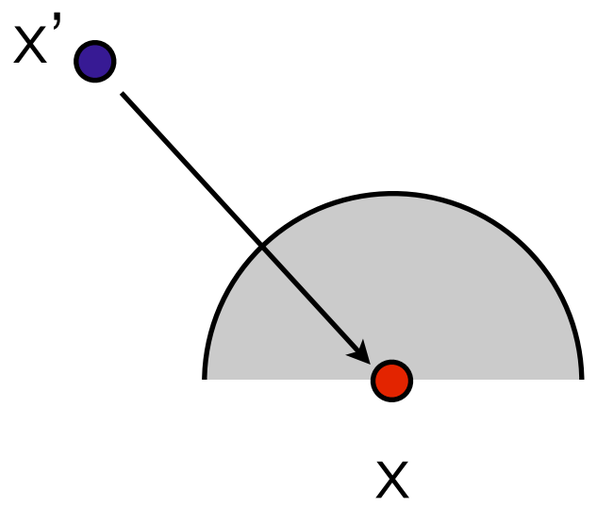

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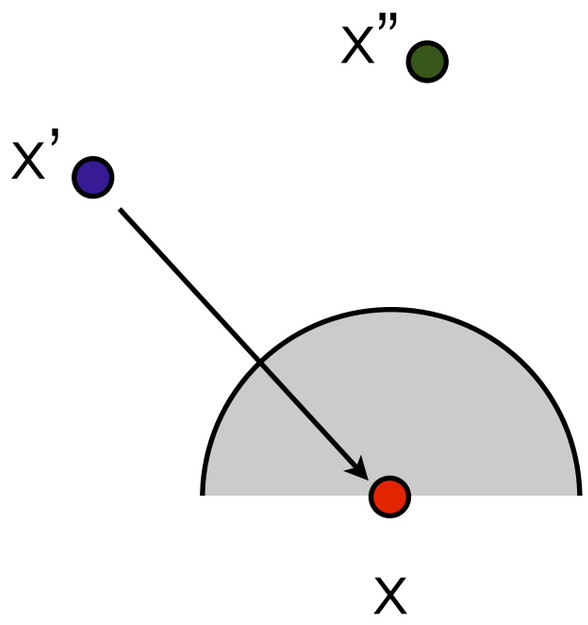

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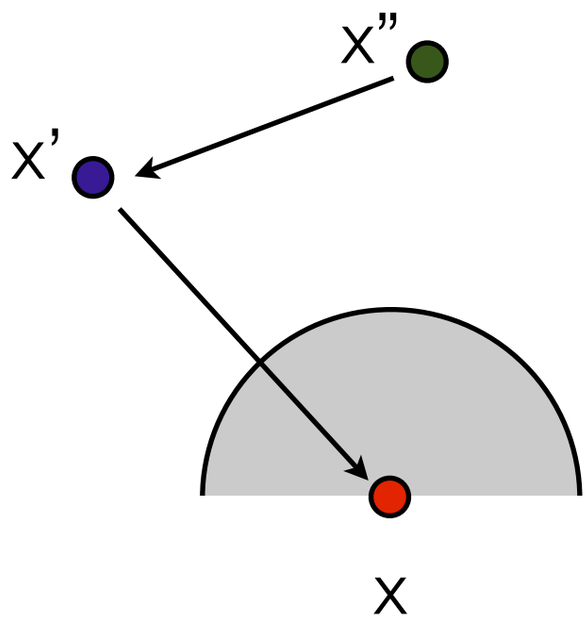

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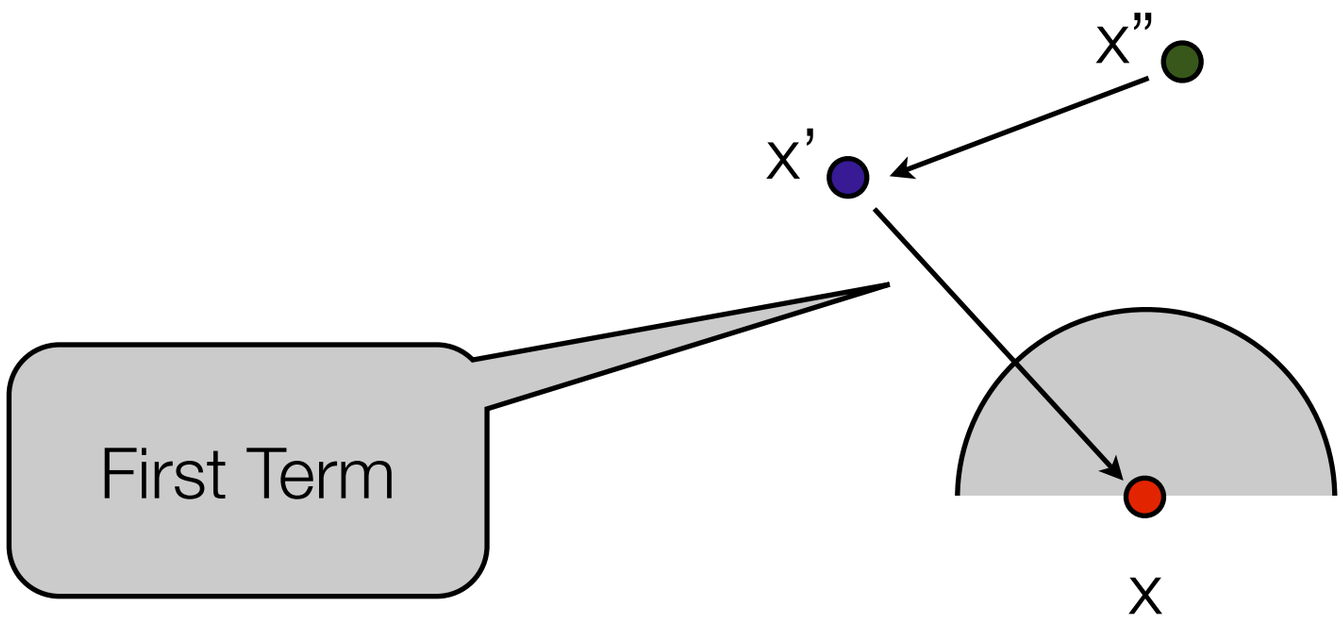

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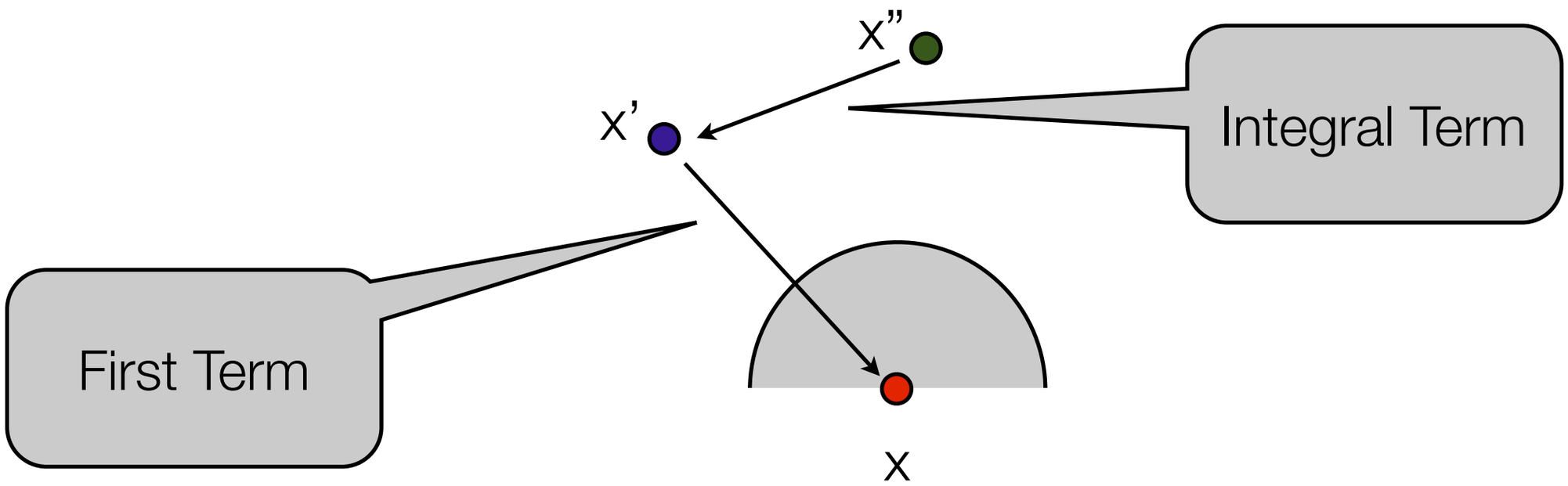

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  - In fact, point x is every point in the scene !
  - View-dependent representation - can help in reducing the complexity of the solution
- Recursive equation
  - Find I(x’,x”) to calculate I(x,x’)
  - Leads to an elegant **path tracing** algorithm for light transport

Implementing Kajiya's Equation

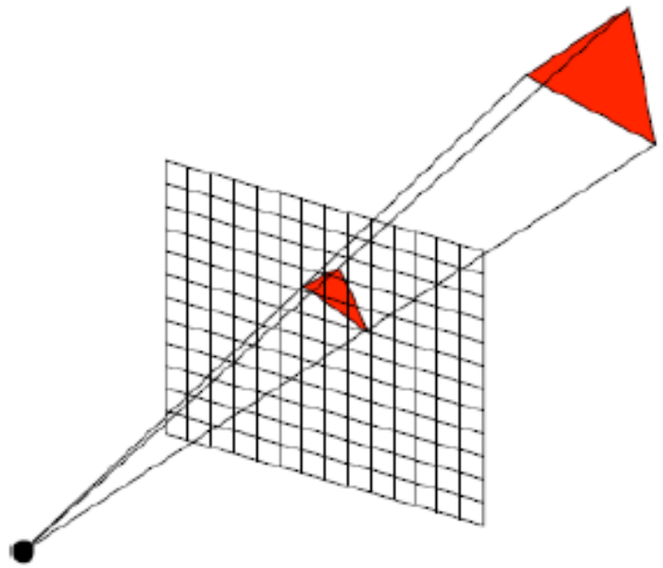
- **Rendering** : visualizing 3D data on 2D screen
- Two main approaches
  - Projective Methods
  - Path Tracing Methods

Projective Vs Ray Tracing

Projective methods:

Object-order rendering, i.e.

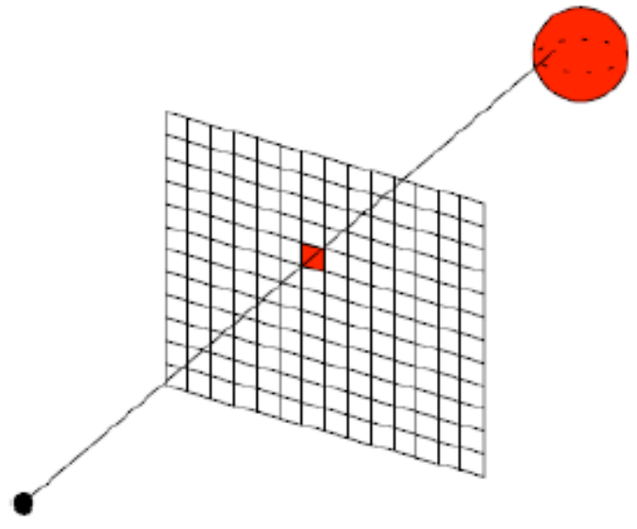
- For each object . . .
- . . . find and update all pixels that it influences



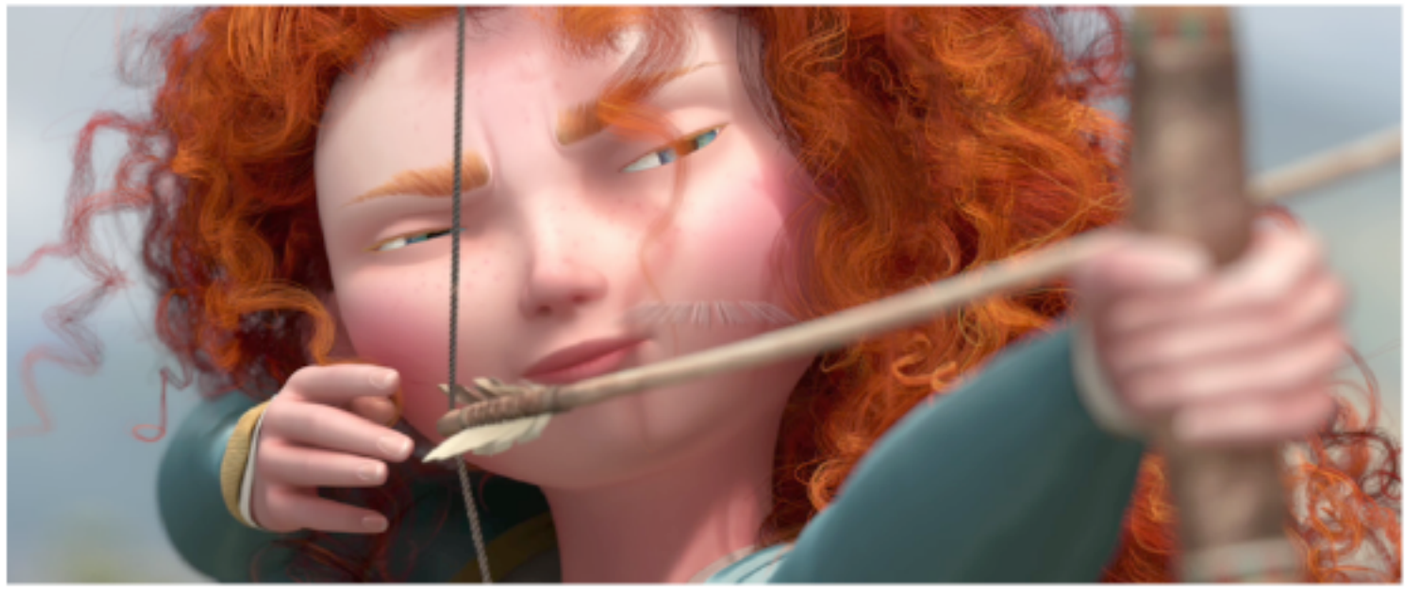
Ray tracing:

Image-order rendering, i.e.

- For each pixel . . .
- . . . find all objects that influence it and update it accordingly



Examples : Ray Traced Rendering

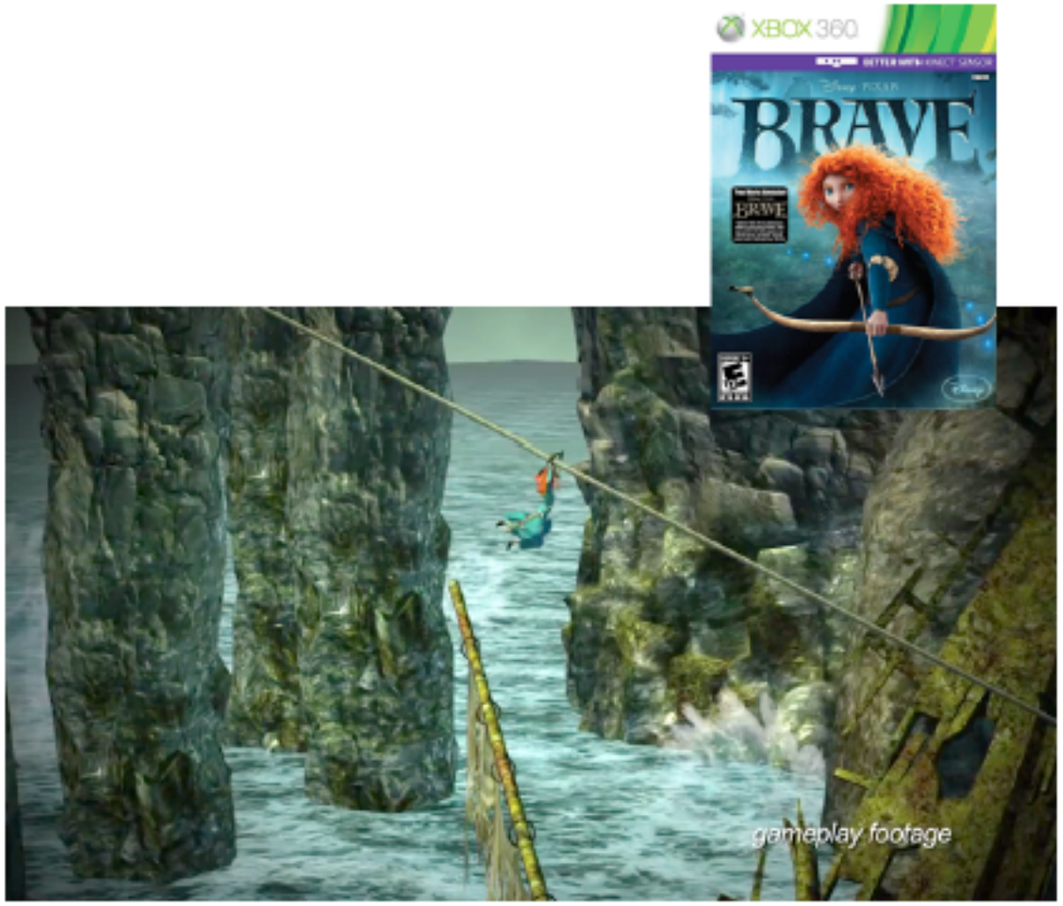


Images courtesy Wolfgang Hürst, Utrecht University

Example : (Real-time) Projected Rendering

Images courtesy Wolfgang Hürst, Utrecht University

Examples : Comparison



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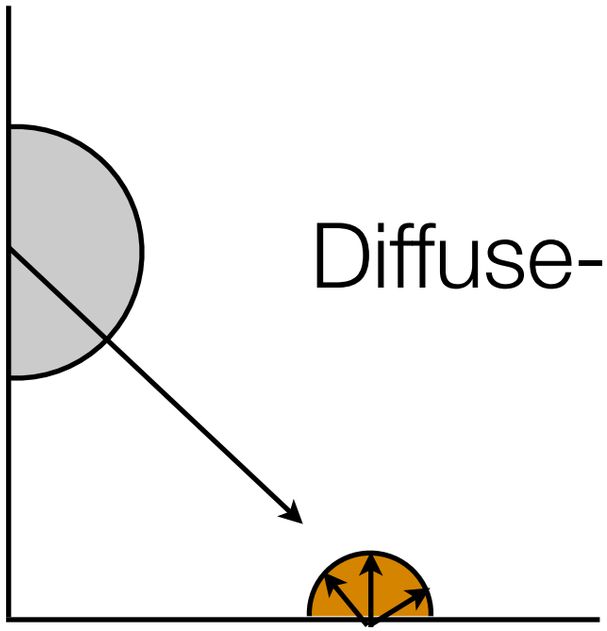
Surface-Light Transport Model

- Categorized based on the surface to surface interactions
- Non-mathematical organization, enables easy comparison between the various algorithms
- One surface (or point) is considered the “source” and another is the “sensor”
- What types of light transport occurs between the source and the sensor
  - Diffuse light - isotropic - same in all directions
  - Specular light - anisotropic - directional behavior

Light Transport Mechanisms

Light Transport Mechanisms



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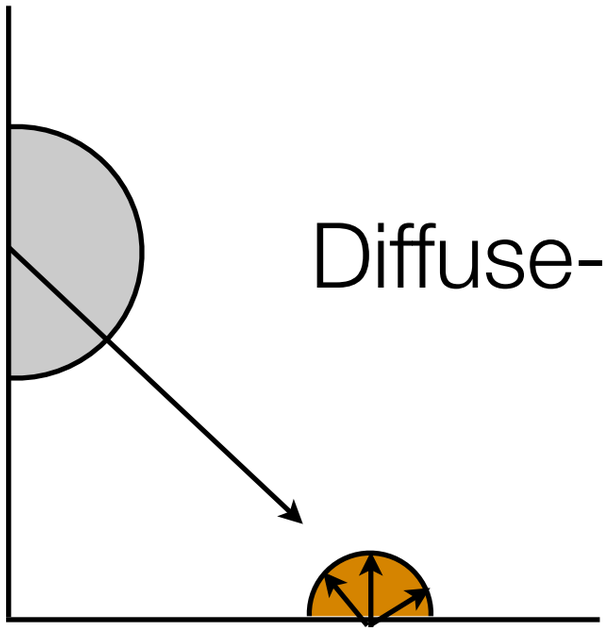
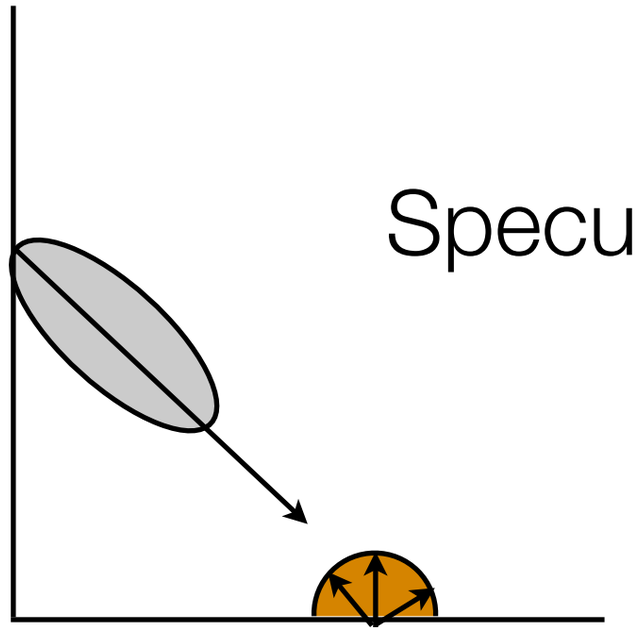


Diffuse-Diffuse



Specular-Diffuse

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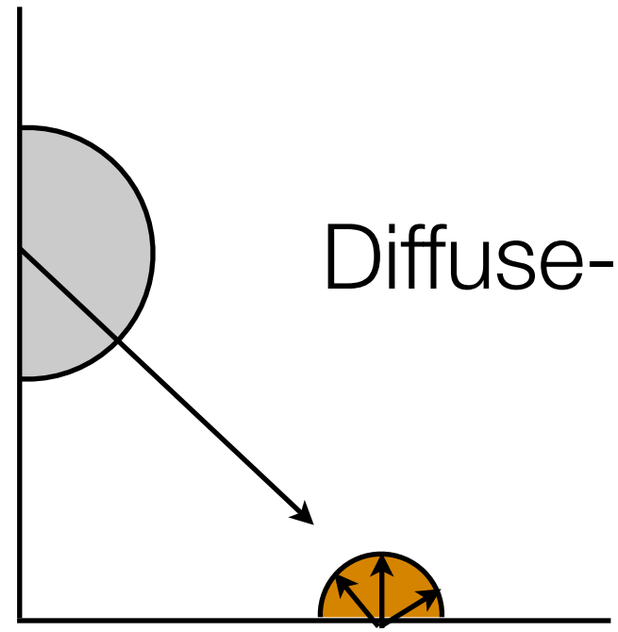

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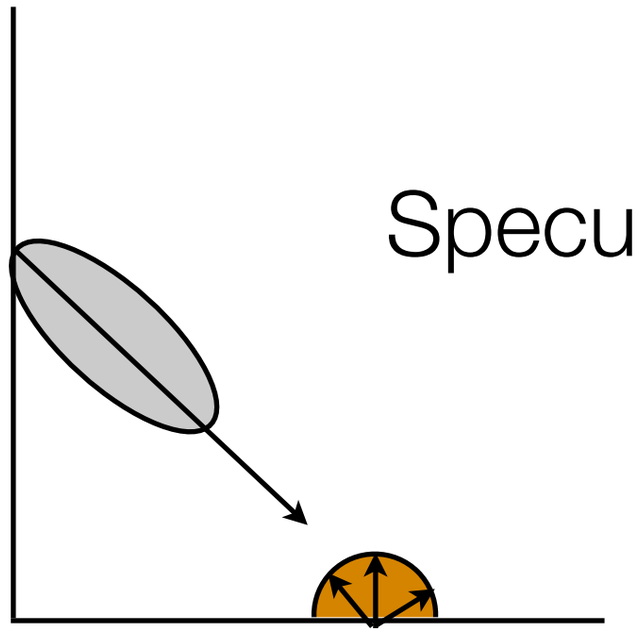
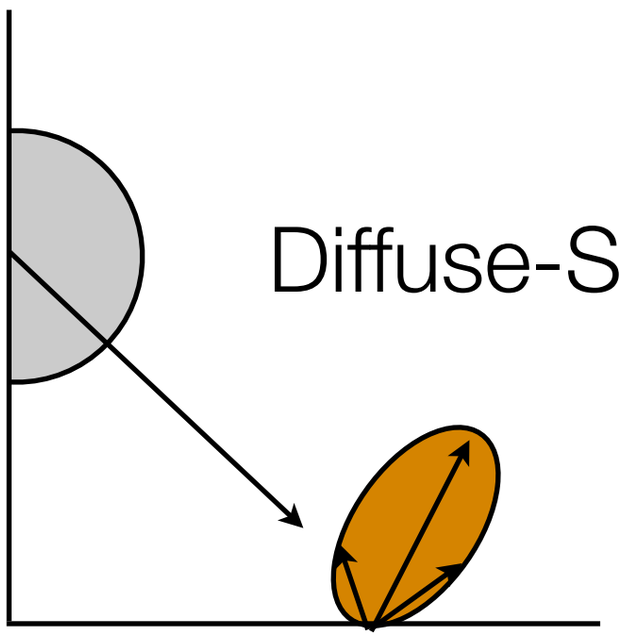


Specular-Diffuse



Diffuse-Specular

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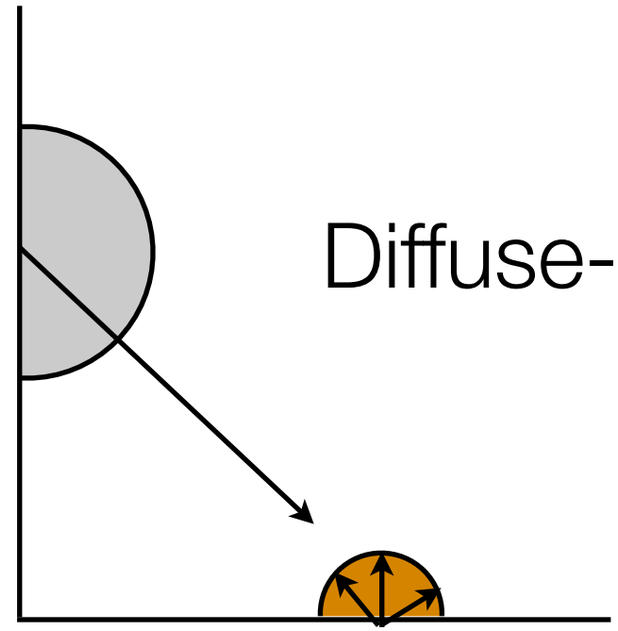

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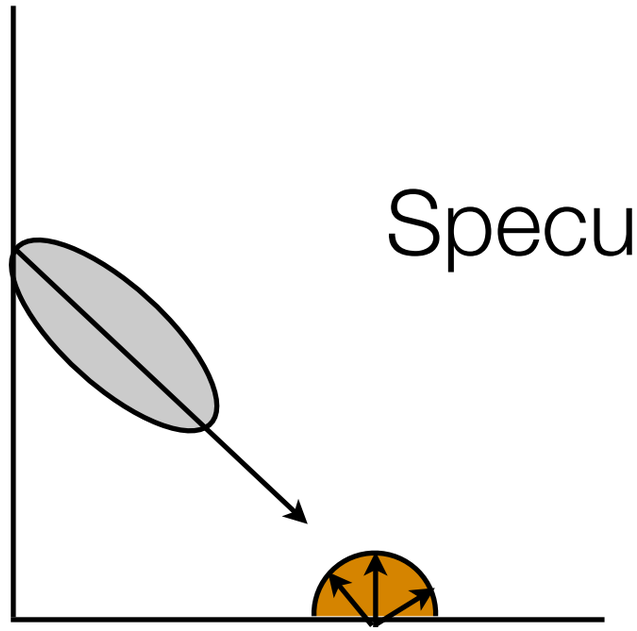

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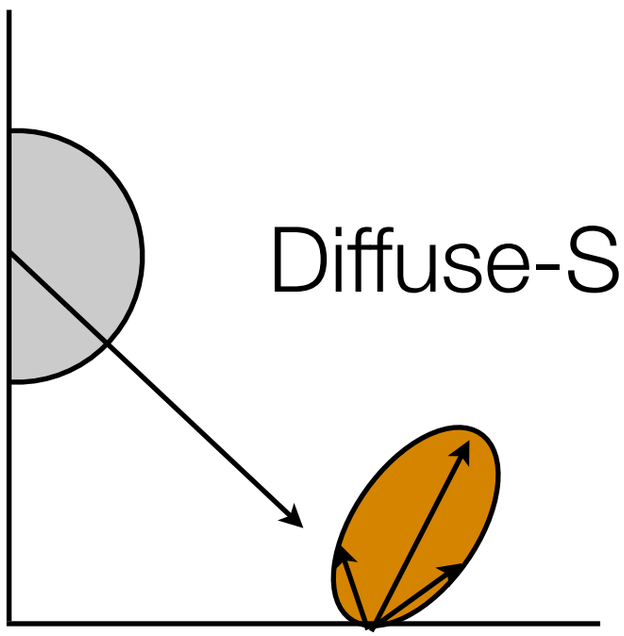

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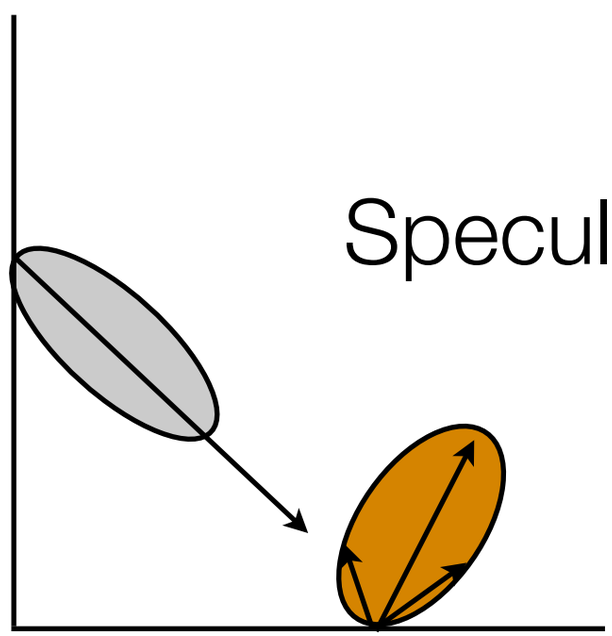

Specular-Specular

Methods to Solve Light Transport Models

- Diffuse - Diffuse
  - Only diffuse surfaces exist in the scene (Matte finish)
  - Radiosity methods used to “solve” for the equation
- Specular - Specular, Specular - Diffuse
  - Shiny surfaces with reflective properties
  - Ray-tracing methods

Simplifying the Light Contribution

- Three components
  - Ambient
  - Diffuse
  - Specular
- Ambient component is assumed to be a constant value in most local illumination models
  - Not observed in practice

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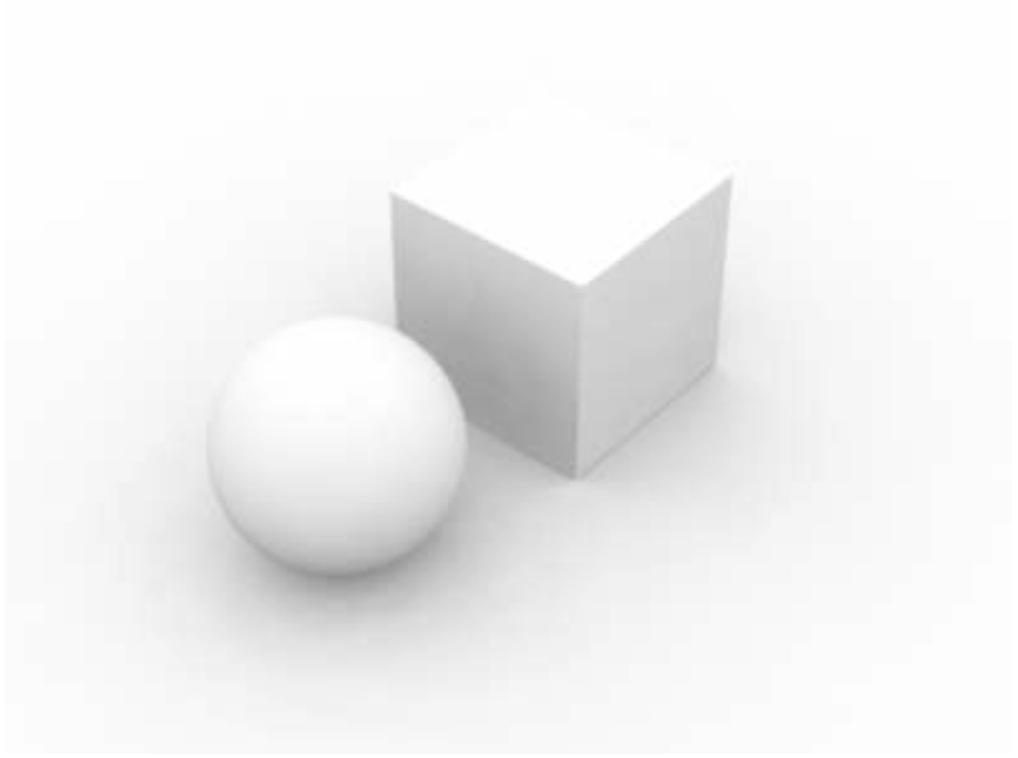

Global Vs Local Diffuse-Diffuse Interaction

Direct lighting

Global lighting

Dynamic Ambient Component

- Ambient term
  - The irradiance that reaches a point (x) as the summed contribution of the diffuse and specular emissions from all other points in the scene
- General effect - occluded parts of the scene are darker than the exposed portions
- Ambient occlusion (AO) computed by ray-tracing approaches
  - Very slow

Screen Space Ambient Occlusion

Motivation

- Accurate AO calculation is expensive
- Basic idea - Areas that are obscured by other objects are darker than those that are not
- Manipulation of intensity levels
- Can be approximated with screen space methods

Is SSAO necessary?

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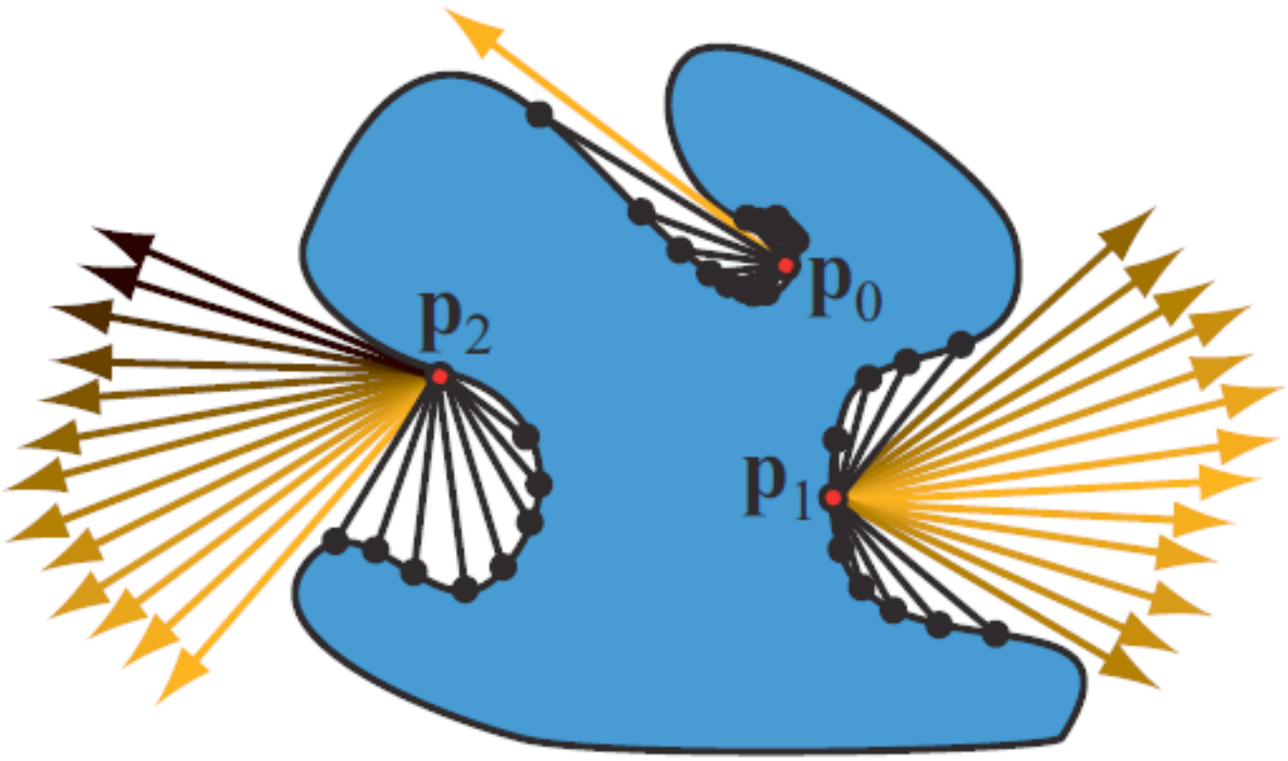
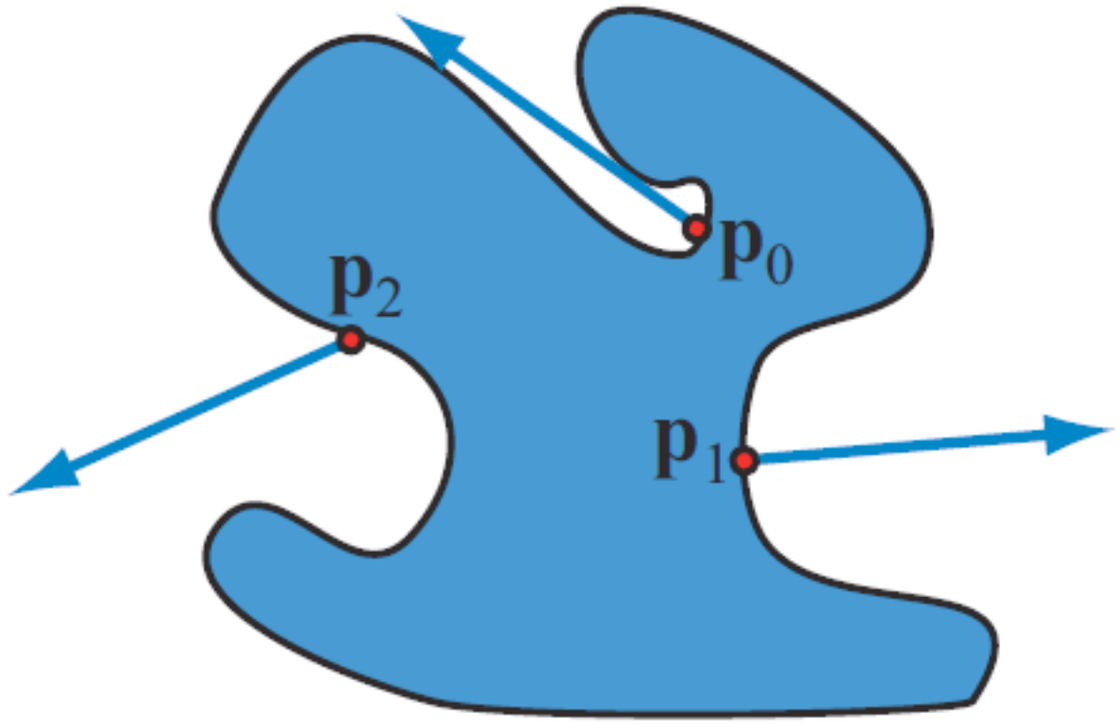
Ambient Occlusion - Ray Cast Solution

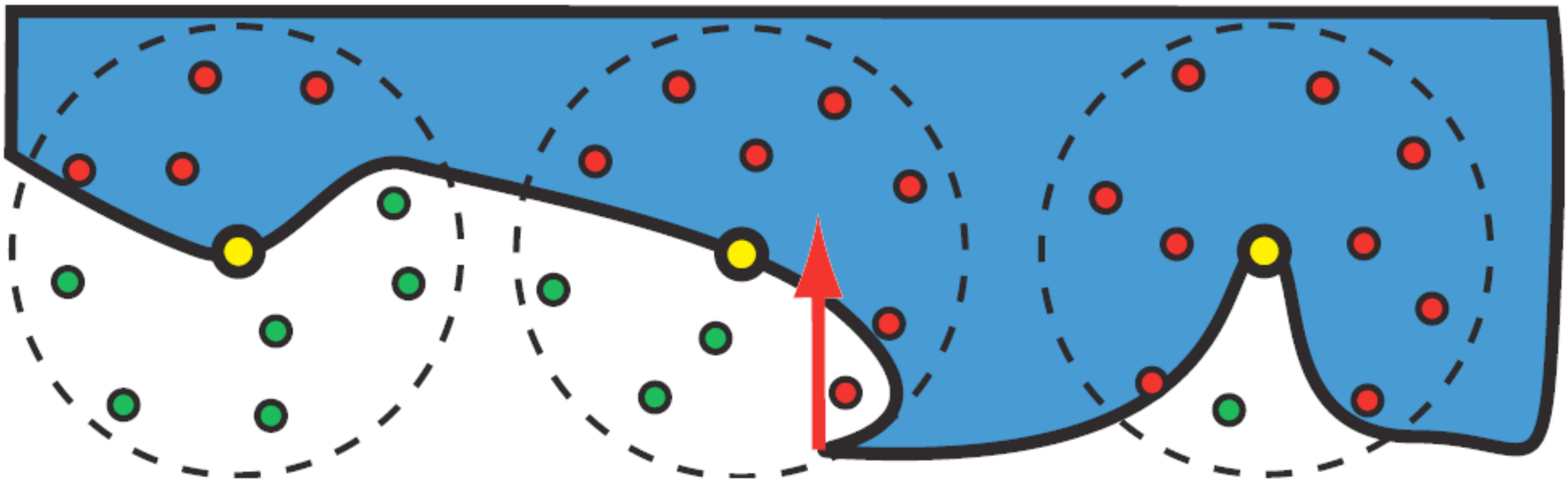
- For every point on the surface
  - Cast a set of rays in all directions surrounding the point
  - Count how many rays continue unobstructed towards the viewer
    - Can be replaced by a threshold distance
  - Use the proportion of obstructed rays as a measure of “occlusion” from surrounding surfaces

Computing Occlusion





Screen Space Ambient Occlusion
Overall Idea



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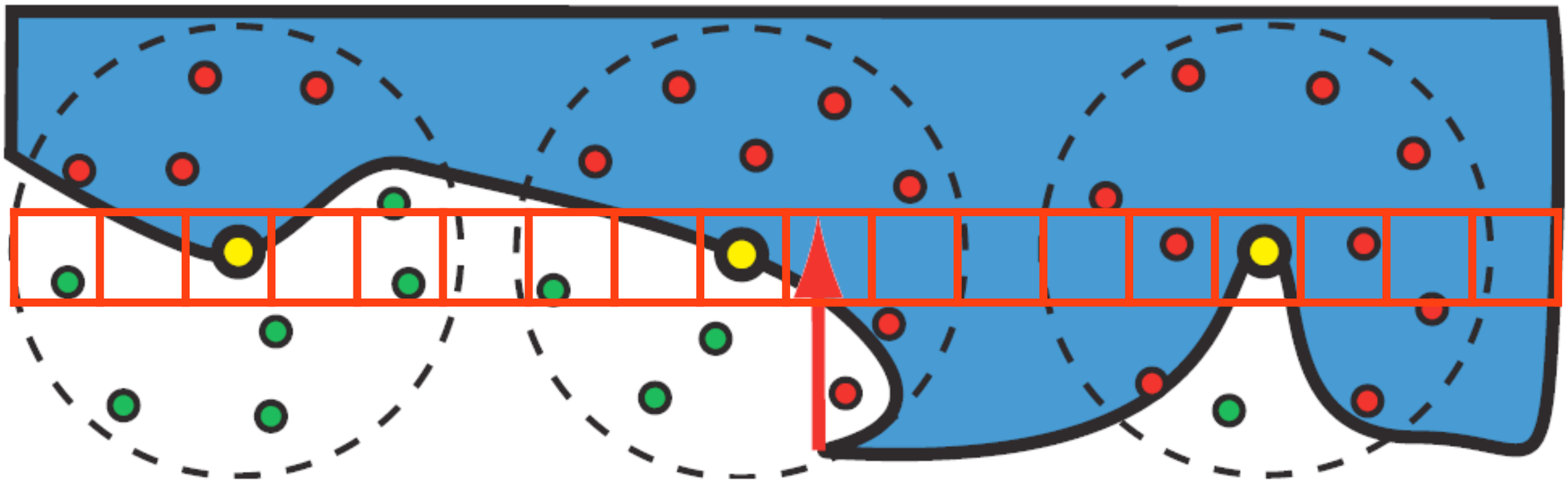

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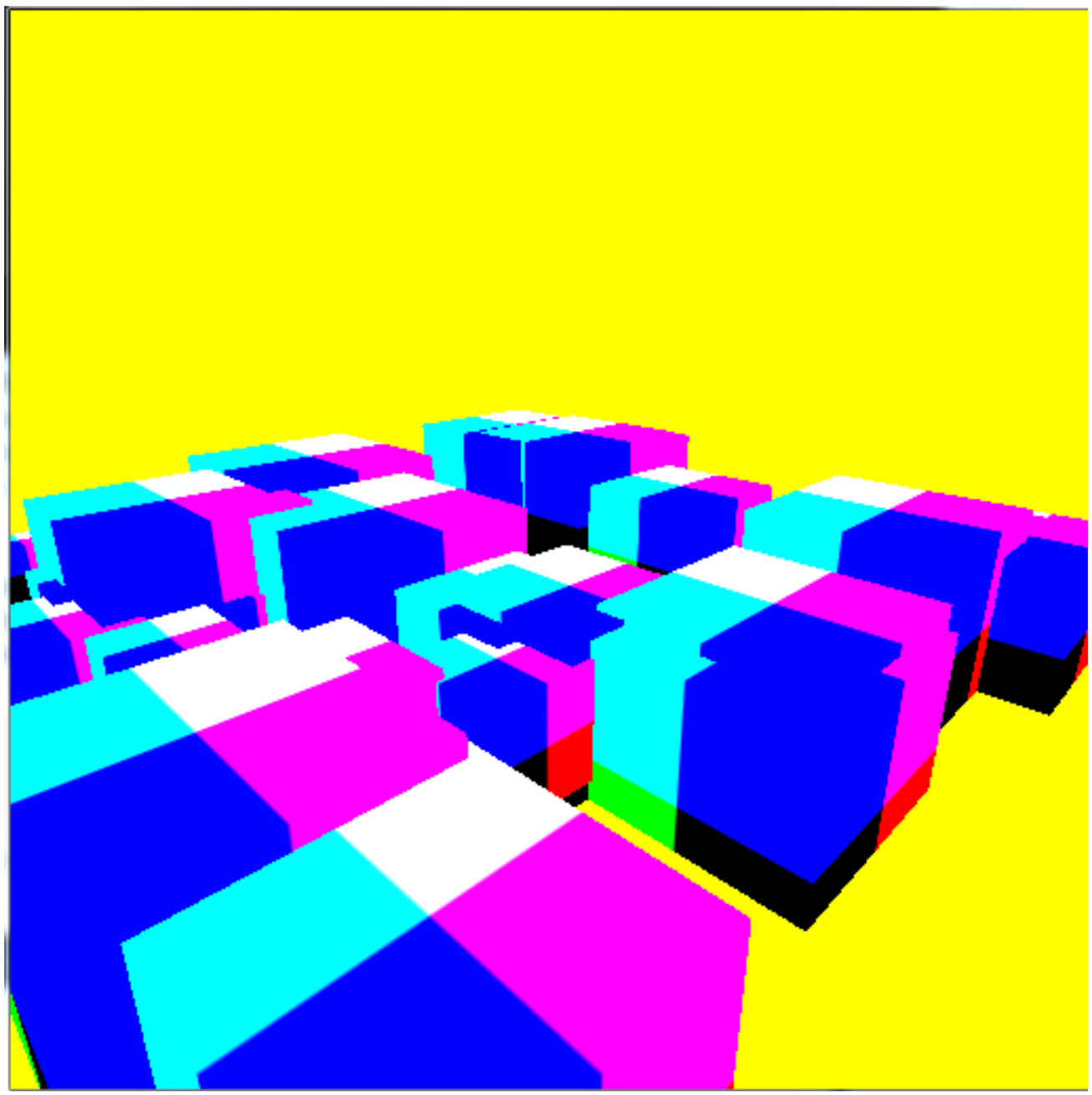
  - Compute a “blocking factor” to attenuate the light values

Algorithm

- Multi-pass implementation
- Needs render-to-texture functionality
- First pass
  - Render the 3D scene
- Subsequent passes
  - Render a fullscreen quad to process the fragments

Example Scene



3D Cubes

Color = local coordinate values

Pass 1 (Fragment Shader)

- Inputs
  - Camera position
  - Eye space position
  - Eye space normals
  - Projection matrix
  - 7x7 matrix of random values

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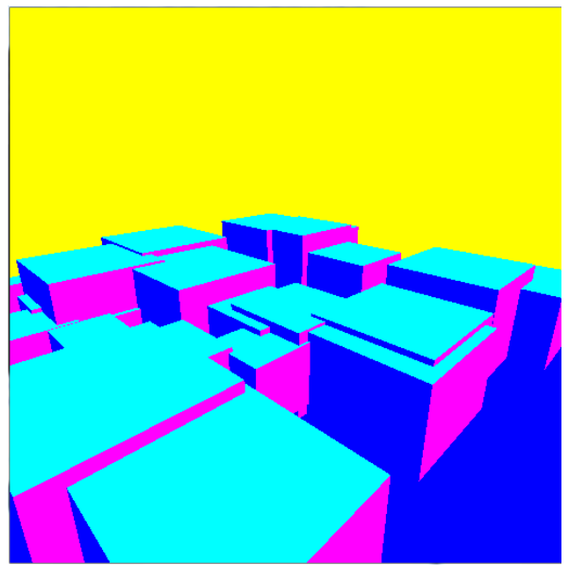

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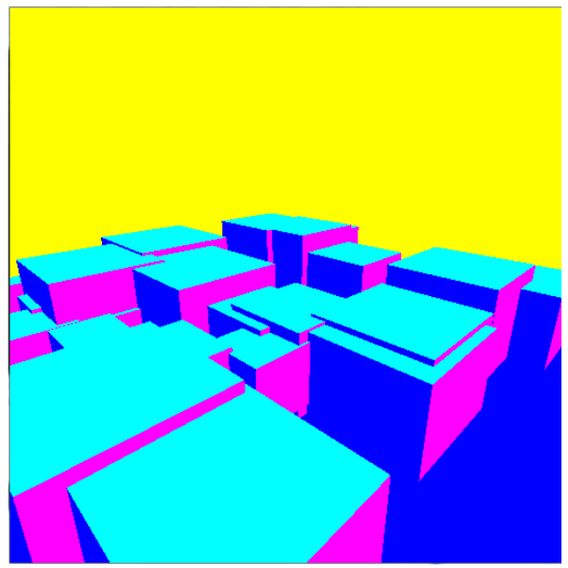
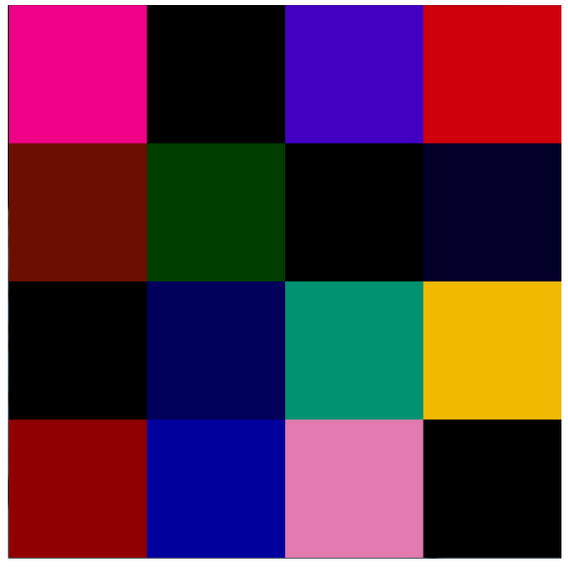




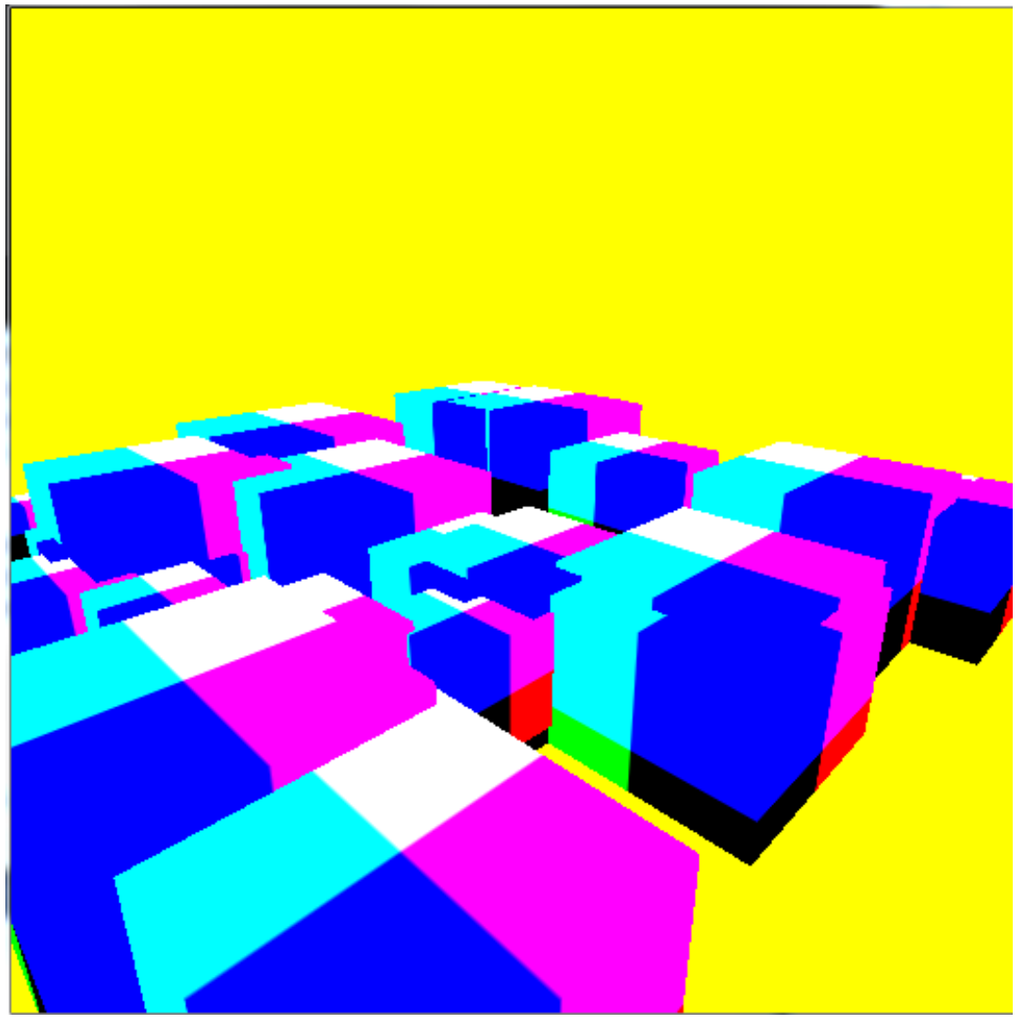
Calculating the “Blocking Factor”

- Generate random offset vectors in a sphere, around the point under consideration
- Compare the depth values for the fragment and the neighbor at the random offset
- Calculate the blocking factor based on the depth comparison
- (In supplied code) blocking factor is calculated as a cumulative function of the z-depth difference between the point and its neighbors

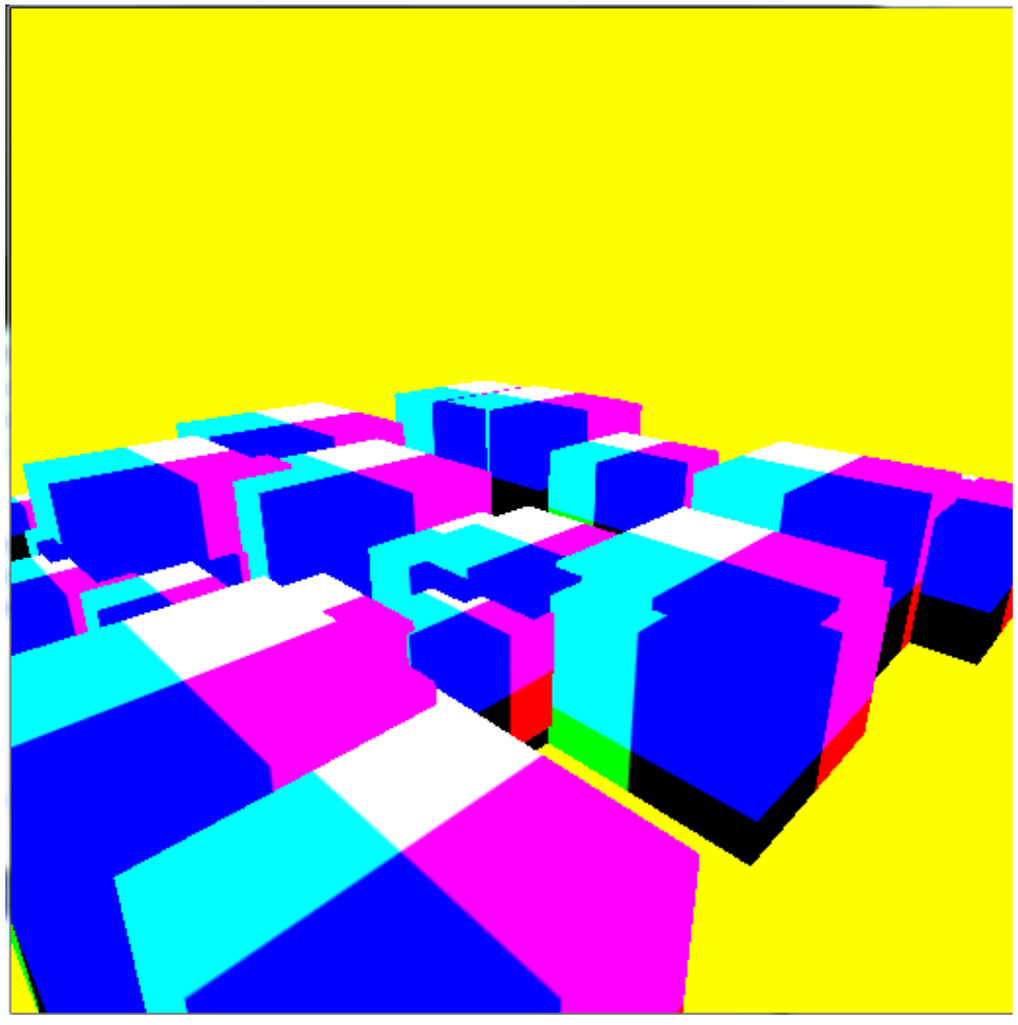
GLSL Code Snippet

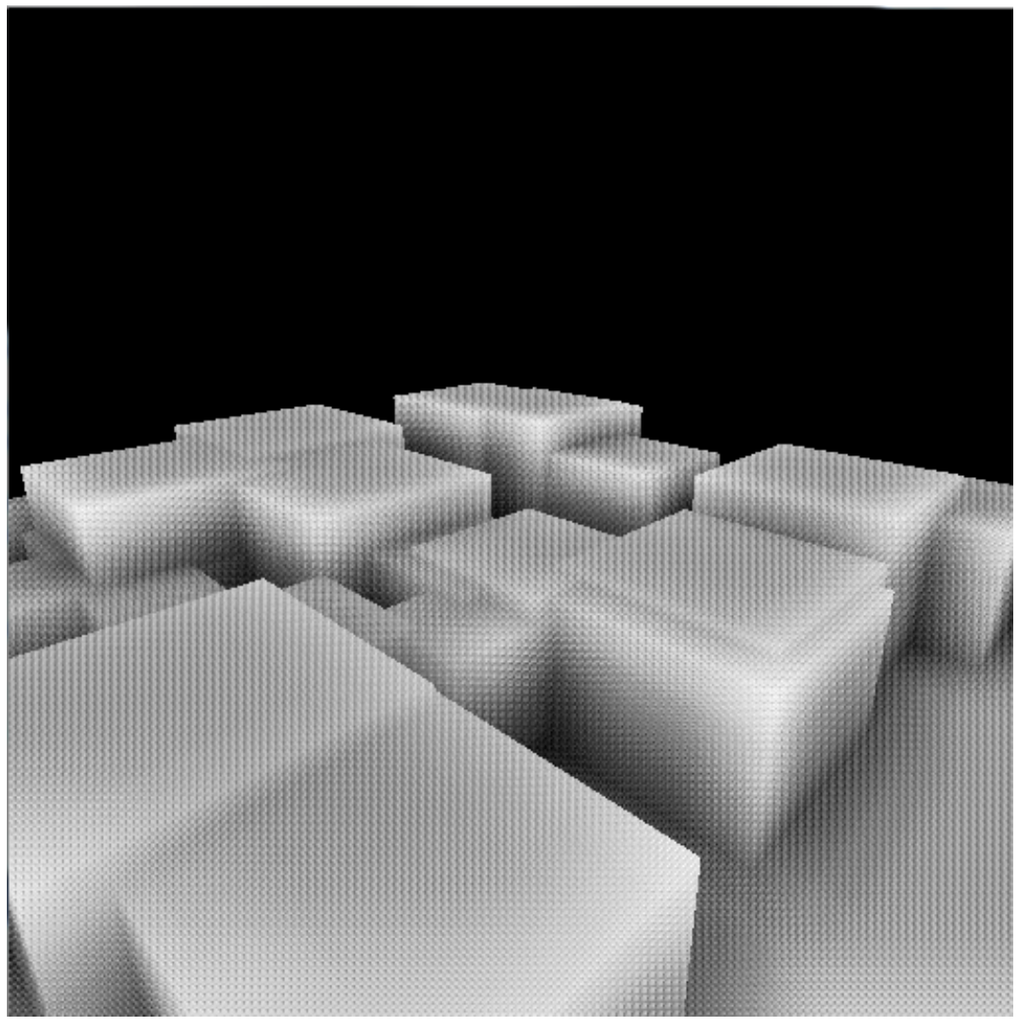
```
// for each sample
    int count = 0;
    for( int samplex = 0; samplex < 7; ++samplex )
    {
            for( int sampley = 0; sampley < 7; ++ sampley )
            {
                vec2 index = vec2( samplex, sampley );
                vec4 rand_lookup = textureRect( rand_values, index );
                vec4 rotated_vector = rotationMatrix * rand_lookup;
                vec4 offset = rotated_vector * radius;
                newPos3d = pos3d + offset;

                vec4 projectedPoint = projectionMatrix * vec4(newPos3d.x, newPos3d.y, newPos3d.z, 1.0);
                vec2 screenPoint =  projectedPoint.xy / projectedPoint.w;

                vec2 depth_lookup = (screenPoint.xy*0.5) + vec2(0.5, 0.5);
                vec3 neighbor_lookup = textureRect( eyeSpacePosition, depth_lookup.xy*512 ).xyz;
                neighbor_lookup.z = -1.0/neighbor_lookup.z;

                 float z_diff = 50.0 * max( 0.0, newPos3d.z - neighbor_lookup.z );
                 block_factor += 1.0 / ( 1.0 + (z_diff*z_diff) );
            }
 }

block_factor /= 49;
block_factor = 1.0 - block_factor;
```

Visualizing the Blocking Factor



Visualizing the Blocking Factor





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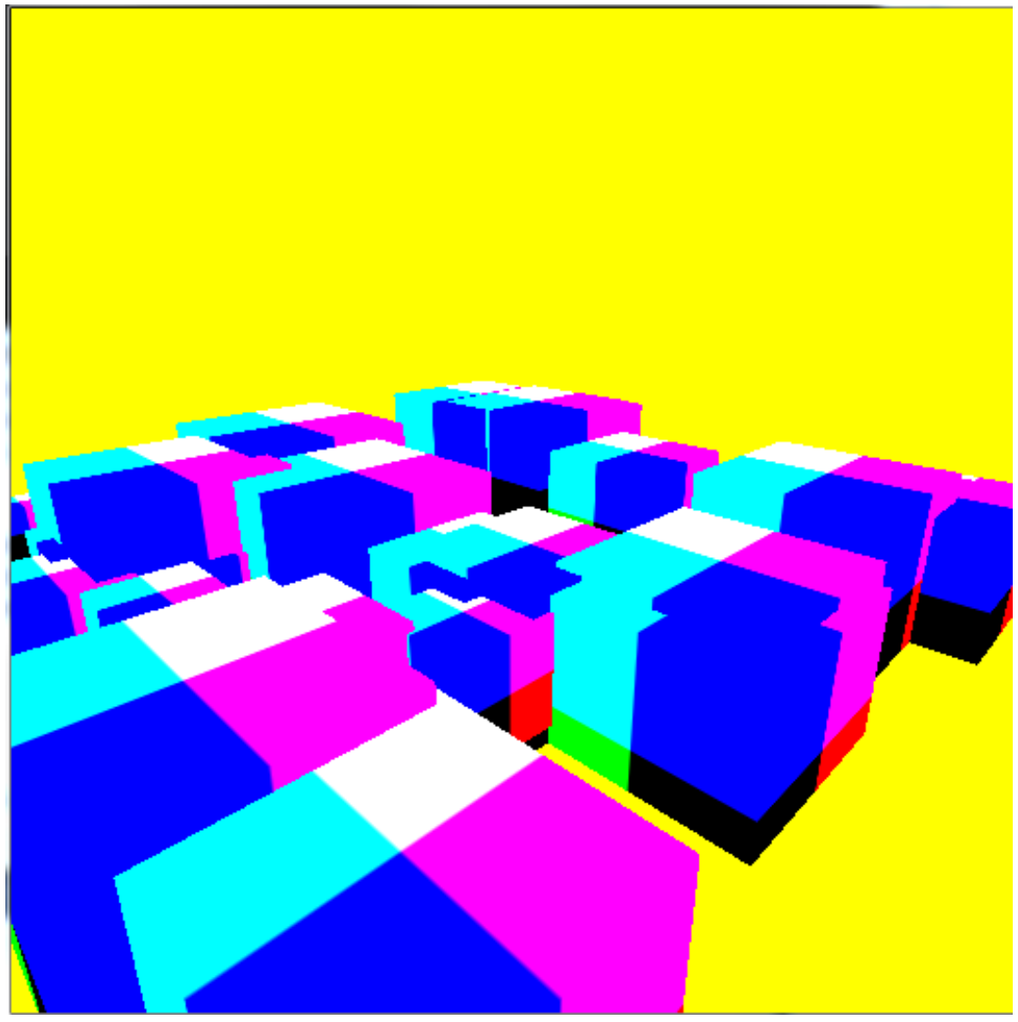

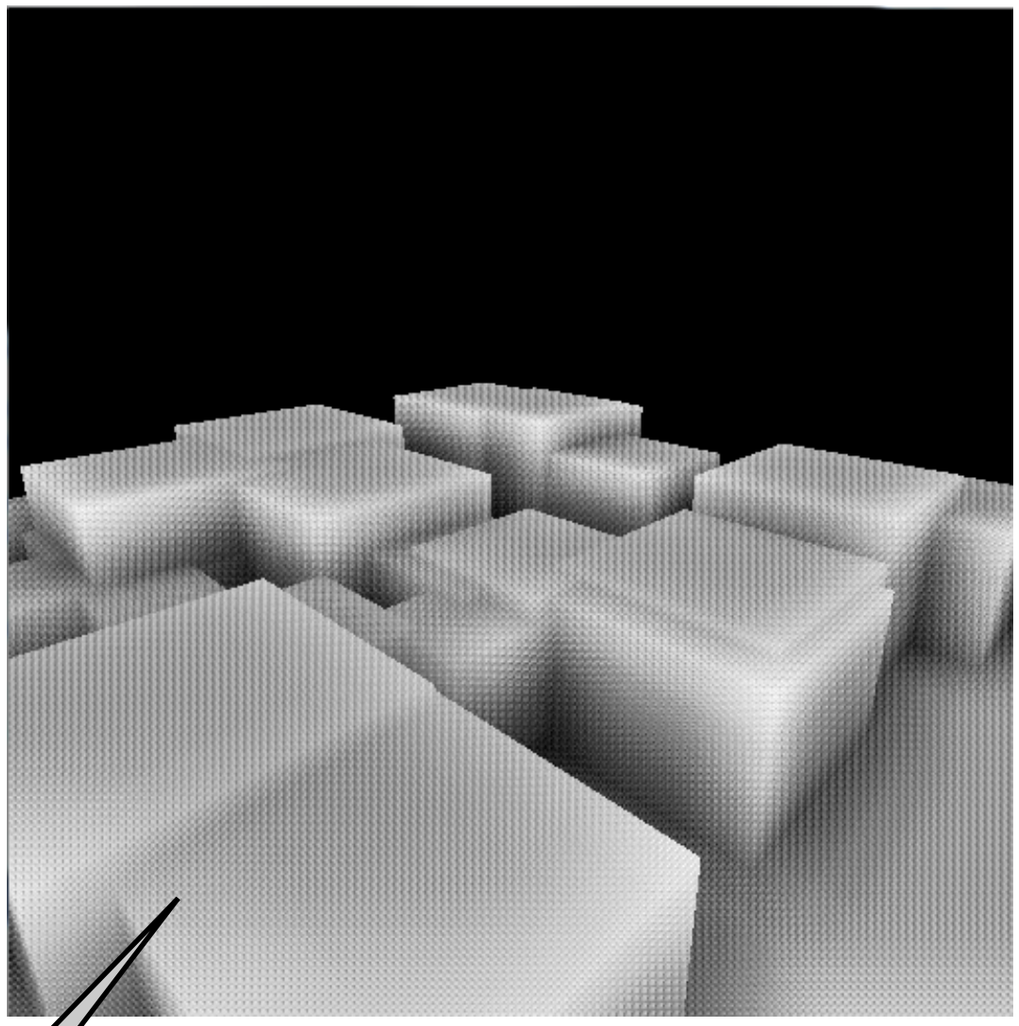

Banding artifacts

Blurring the Blocking Factor

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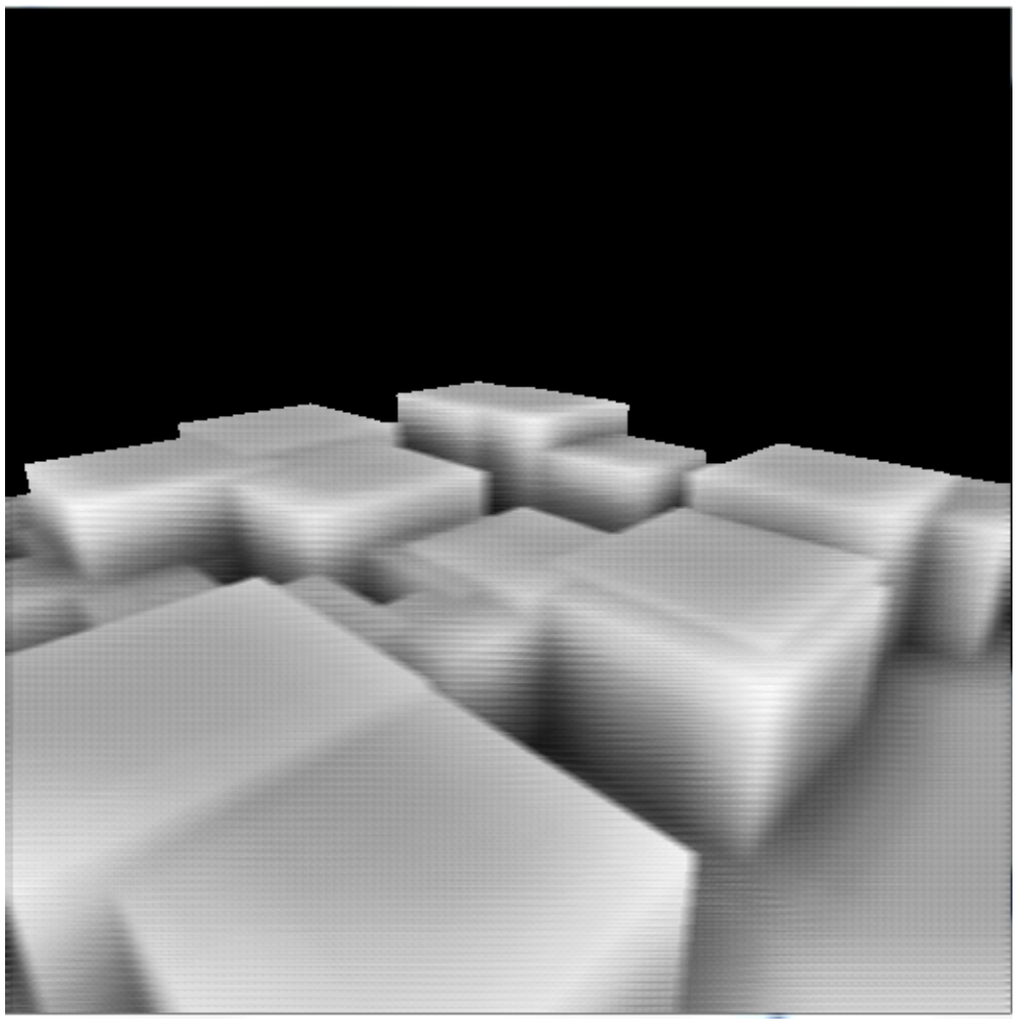

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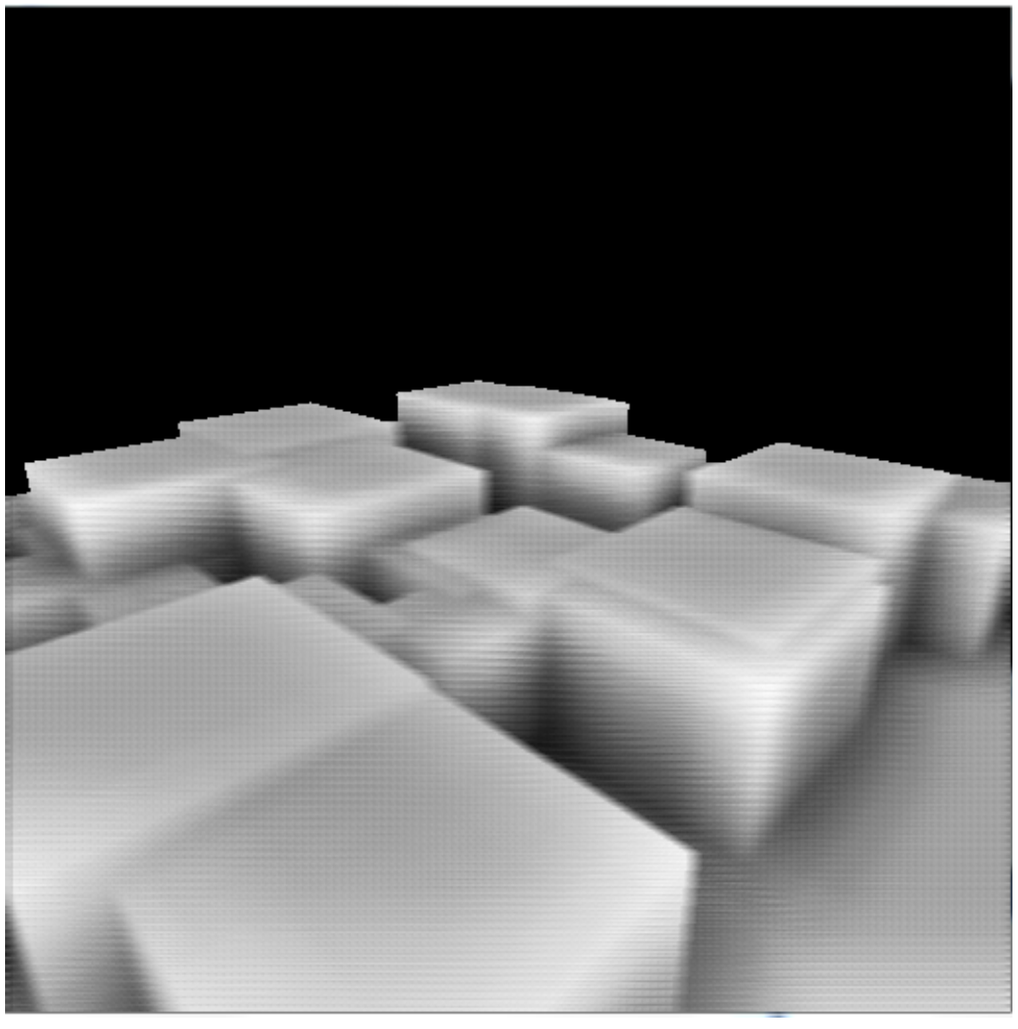
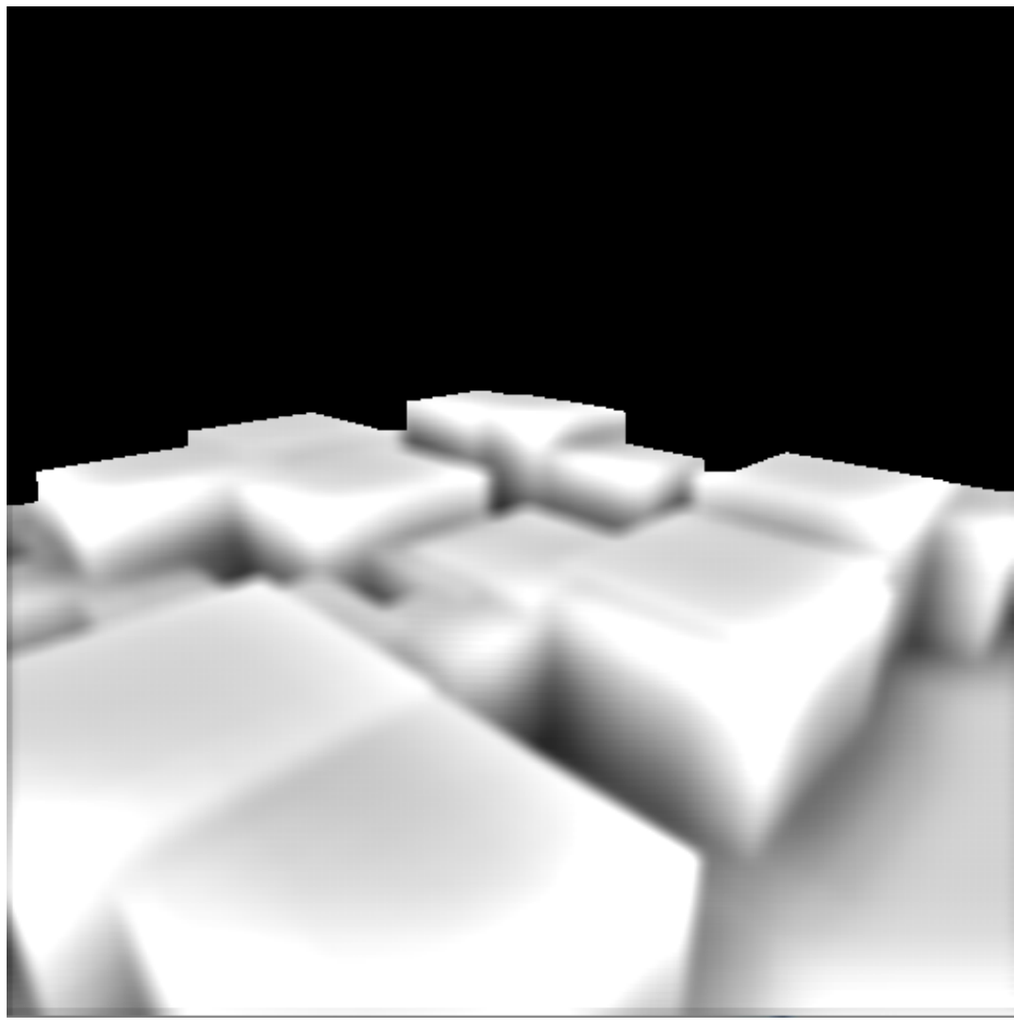
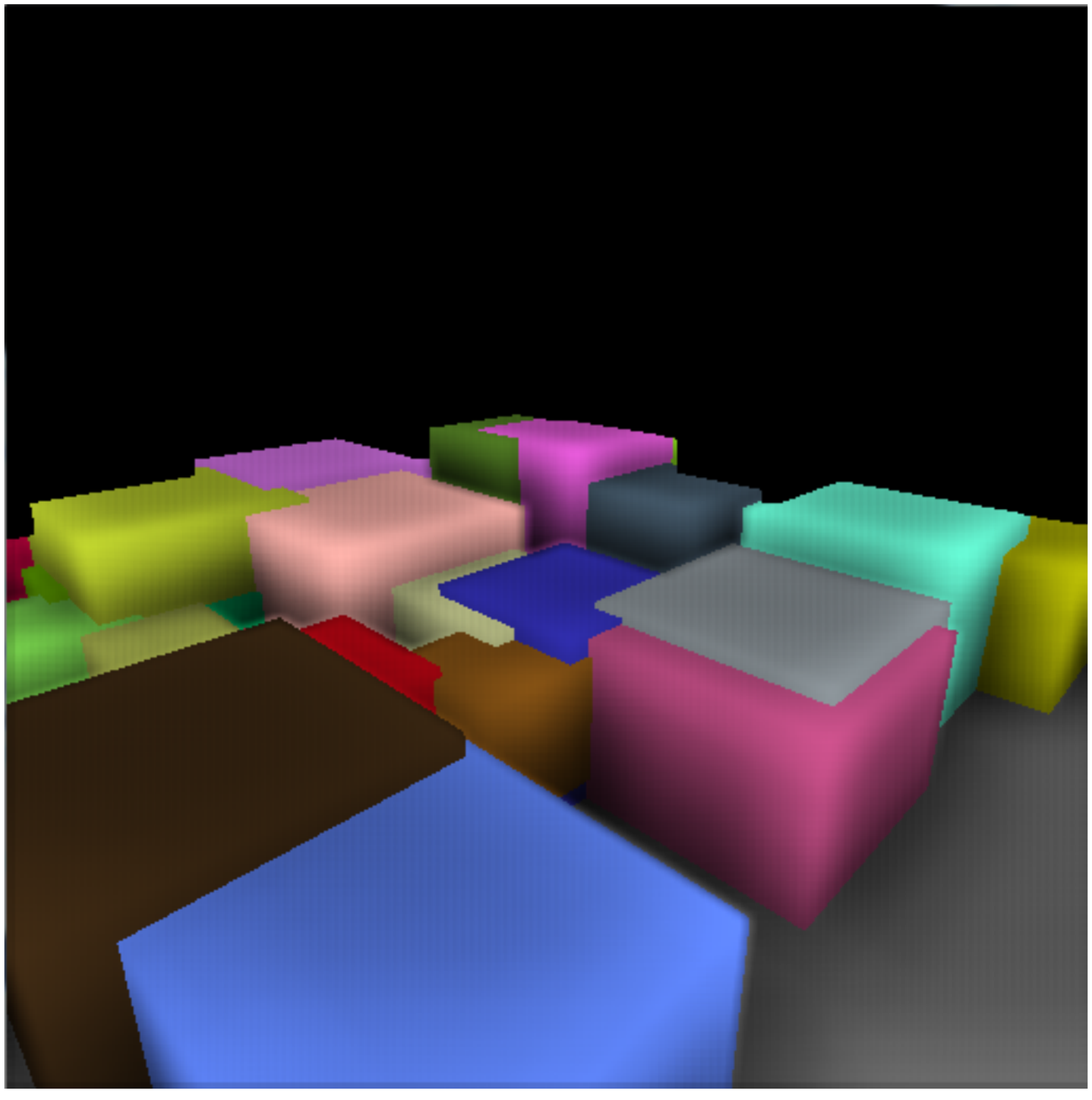




Combining with the Color Values



SSAO Examples

http://www.cyberhead.de/?dev

Crytek - CryEngine 2

Crytek - More Examples

http://video.google.com/videoplay?docid=-2592720445119800709#

Crytek - More Examples

http://video.google.com/videoplay?docid=-2592720445119800709#

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http://video.google.com/videoplay?docid=-2592720445119800709#

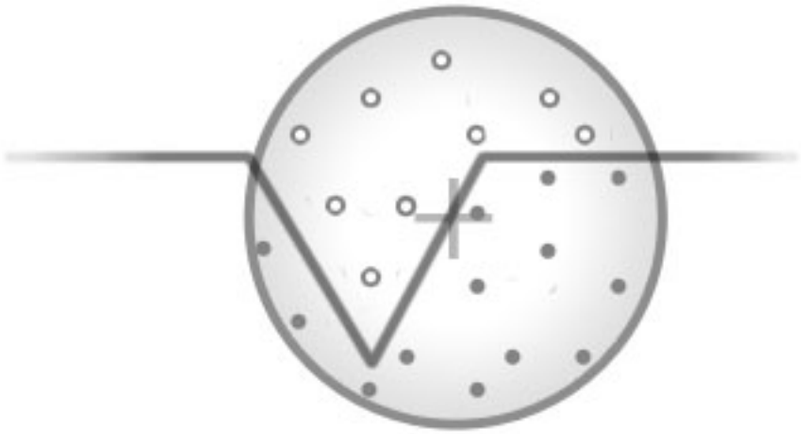
“Up” - Pixar

http://www.awn.com/articles/3d/academy-honors-renderman-getting-point

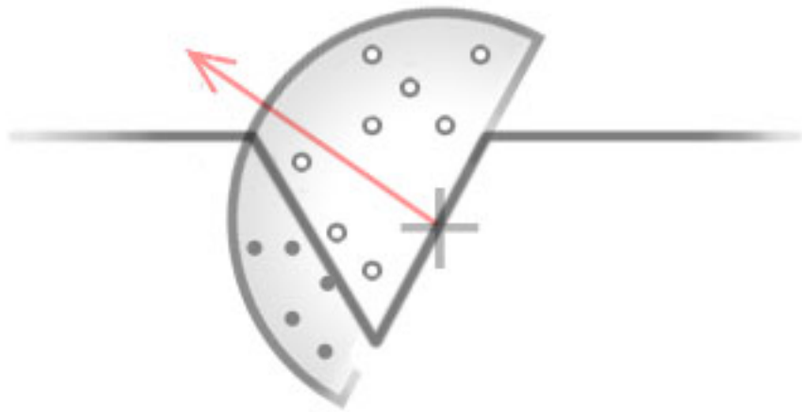
nVidia SDK Demo

Download the Demos from developer.nvidia.com

Extensions



Crytek Method (Full Sphere)



Normal-oriented Method (hemisphere)

https://www.youtube.com/watch?v=-IFxjKT7MXA

References

- SSAO Tutorials / Introduction
  - https://learnopengl.com/#!Advanced-Lighting/SSAO
  - http://john-chapman-graphics.blogspot.com/2013/01/ssao-tutorial.html
- Advanced topics (artifacts in SSAO)
  - https://mtnphil.wordpress.com/2013/06/26/know-your-ssao-artifacts/

Thank You.