

# **Dem Licht auf der Spur**

# Motivation: Architektur



# Motivation: Innenausstattung

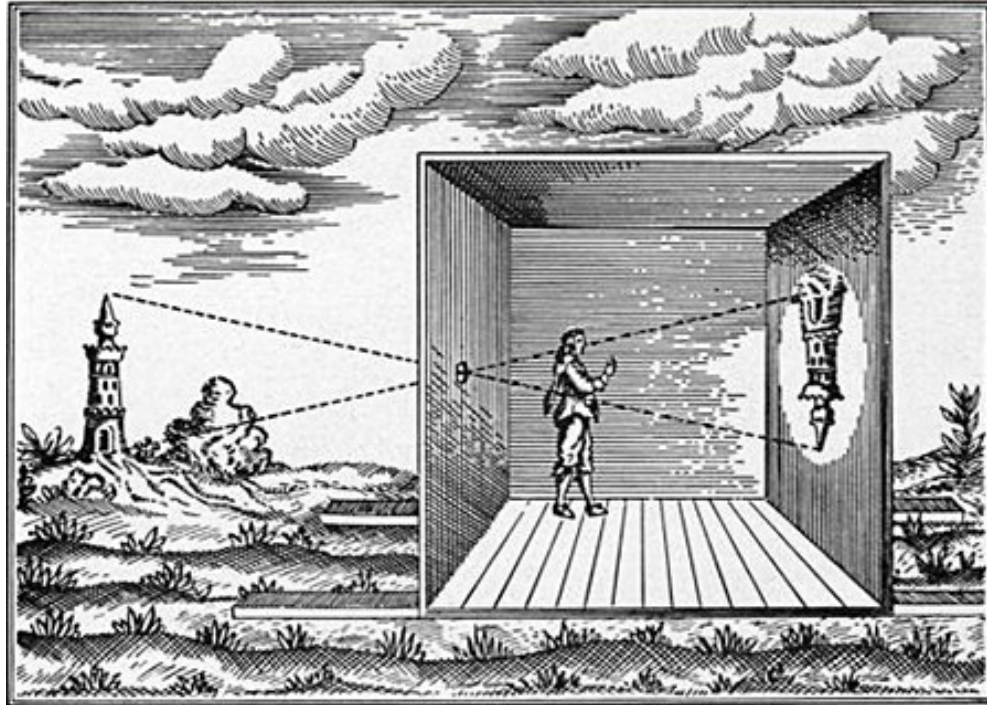


# Motivation: Filme

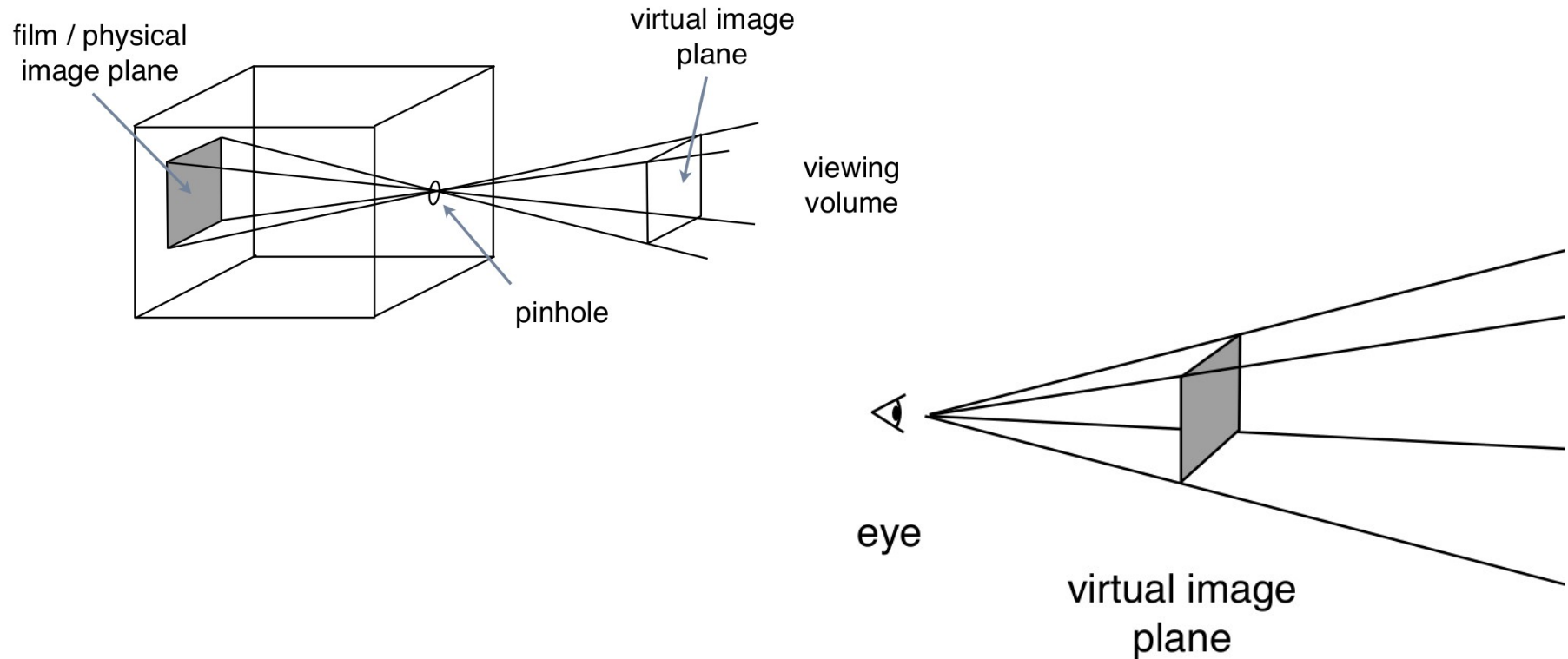




# Lochkamera



# Kameramodell



# Lichtquellen



# Lichtquellen

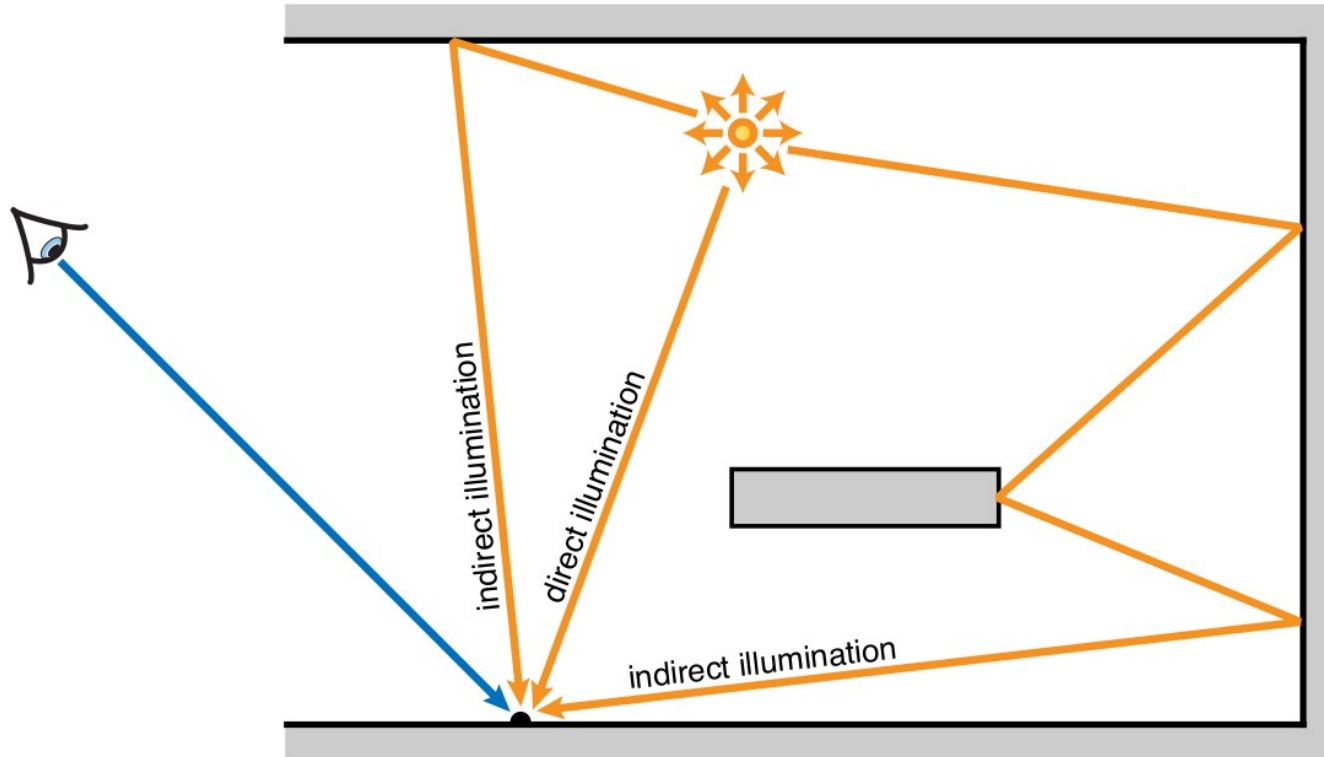


$$L_e(x, \omega_r)$$





# Direktes und Indirektes Licht



# Direktes und Indirektes Licht

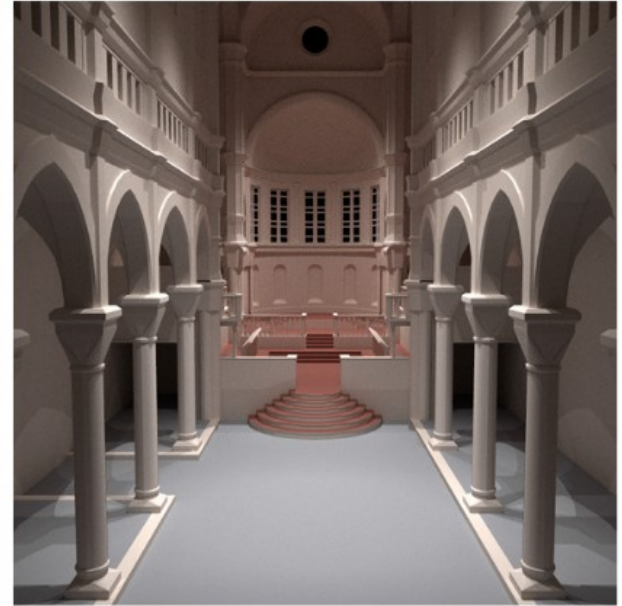
Direct illumination



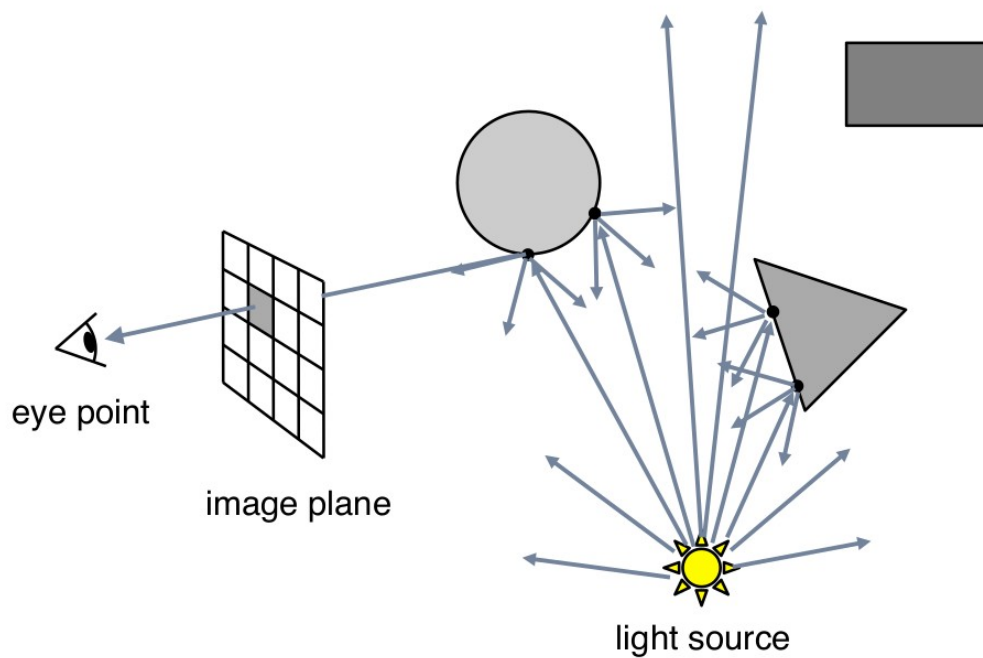
Indirect illumination



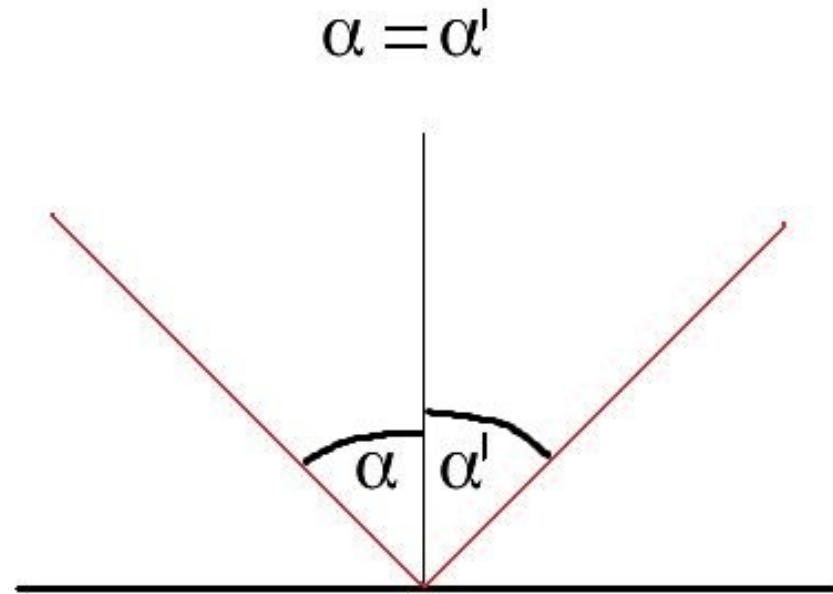
Direct + indirect illumination



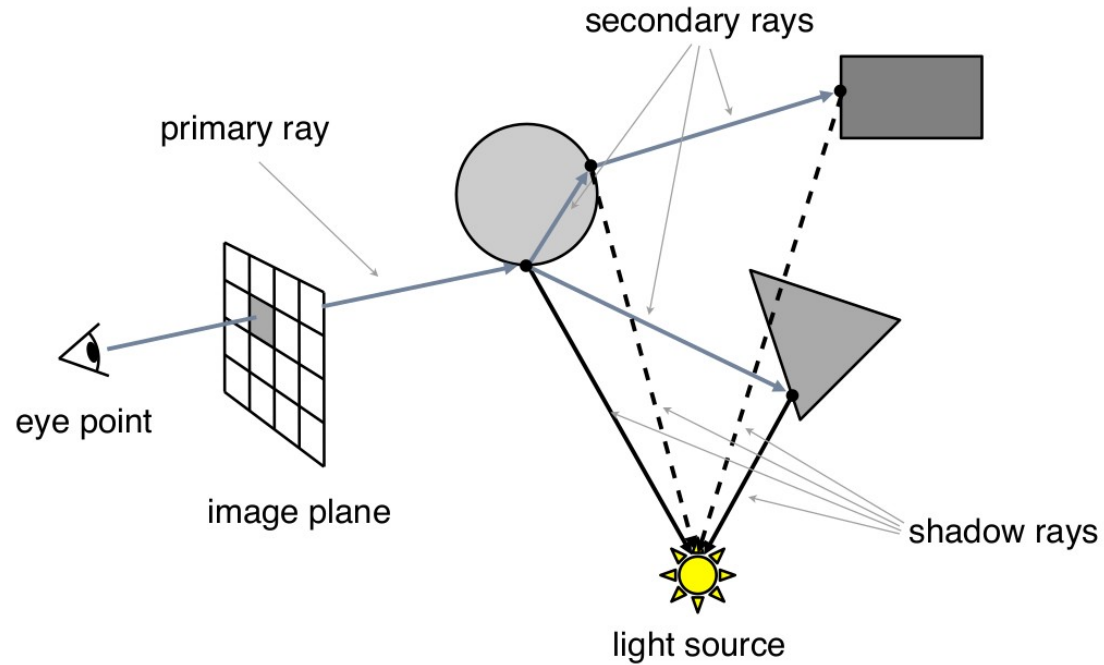
# Light Tracing



# Reflexionsgesetz



# Camera Tracing

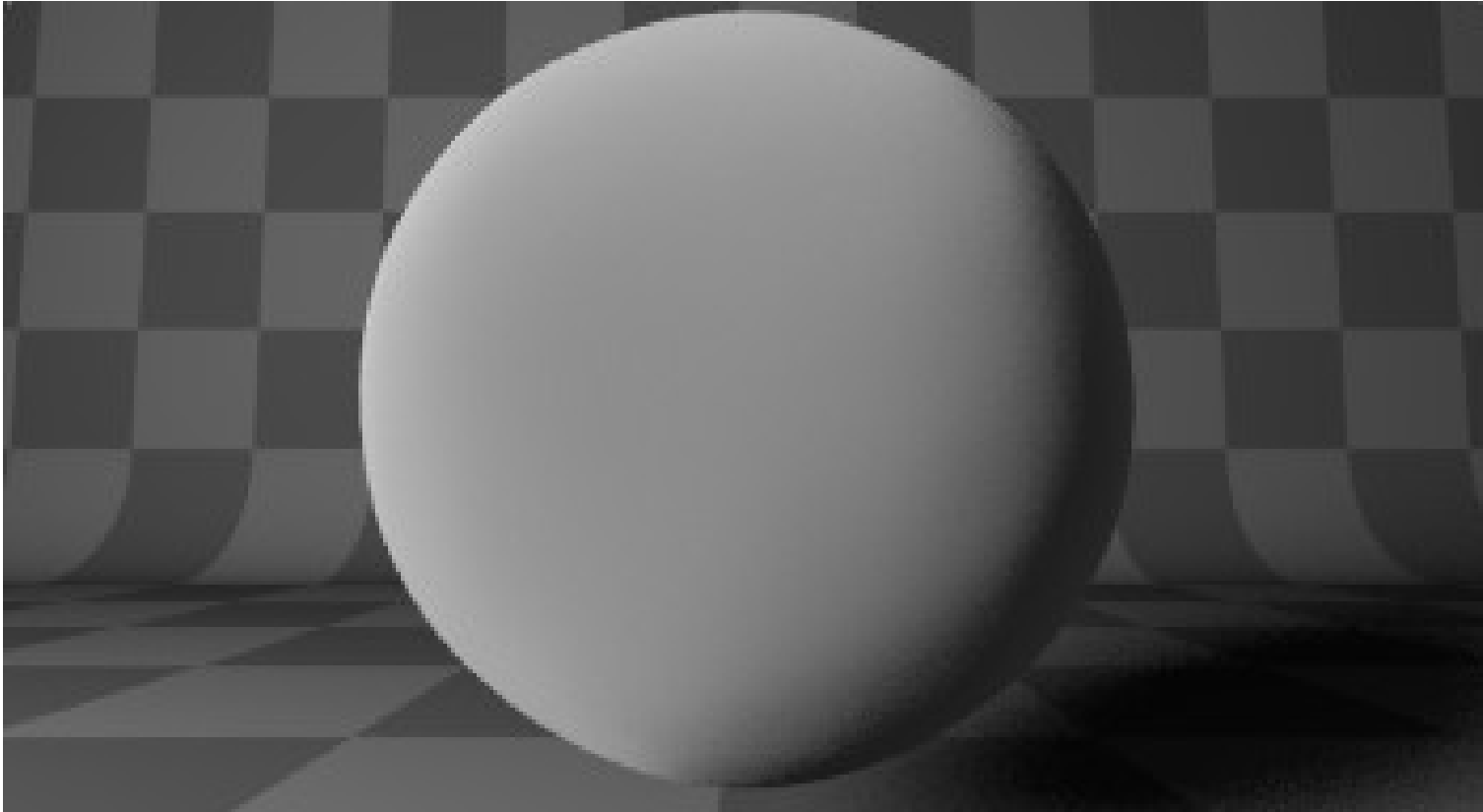


# Glatte Reflexion

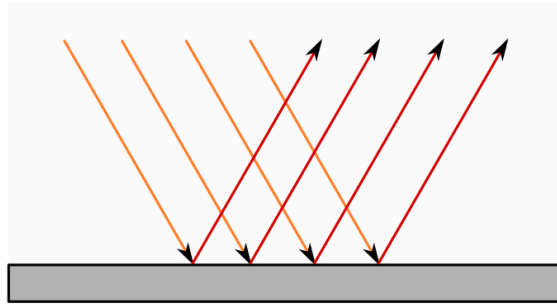




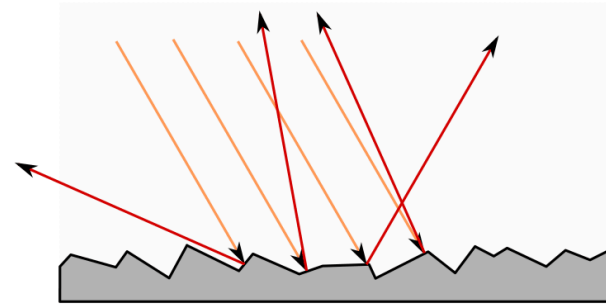
# Raue Reflexion



# Glatte und Raue Reflexion



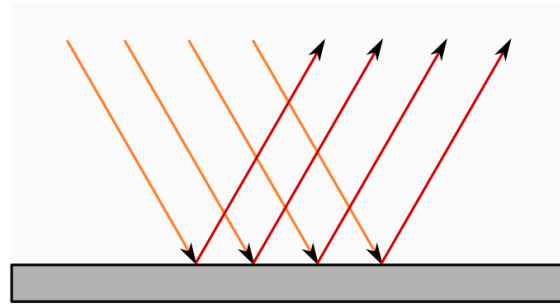
Glatter Spiegel  
Direkte Reflexion



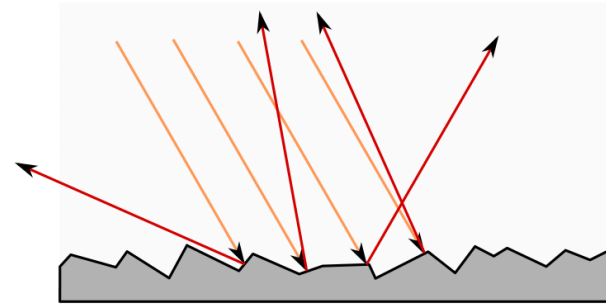
Rauher Spiegel  
Diffuse Reflexion



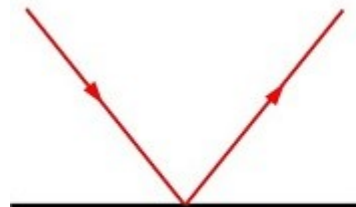
# Glatte und Raue Reflexion



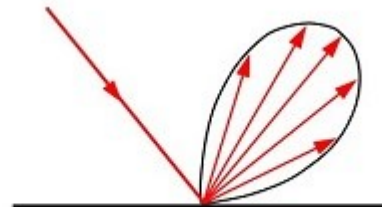
Glatter Spiegel  
Direkte Reflexion



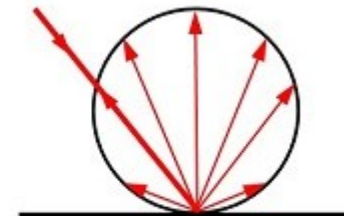
Rauher Spiegel  
Diffuse Reflexion



gerichtet



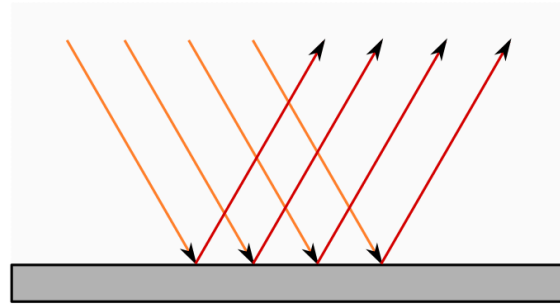
gestreut



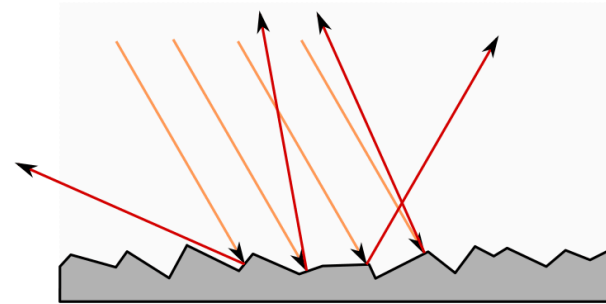
diffus



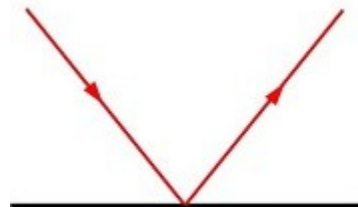
# Glatte und Raue Reflexion



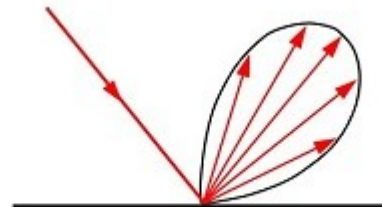
Glatter Spiegel  
Direkte Reflexion



Rauher Spiegel  
Diffuse Reflexion



gerichtet



gestreut

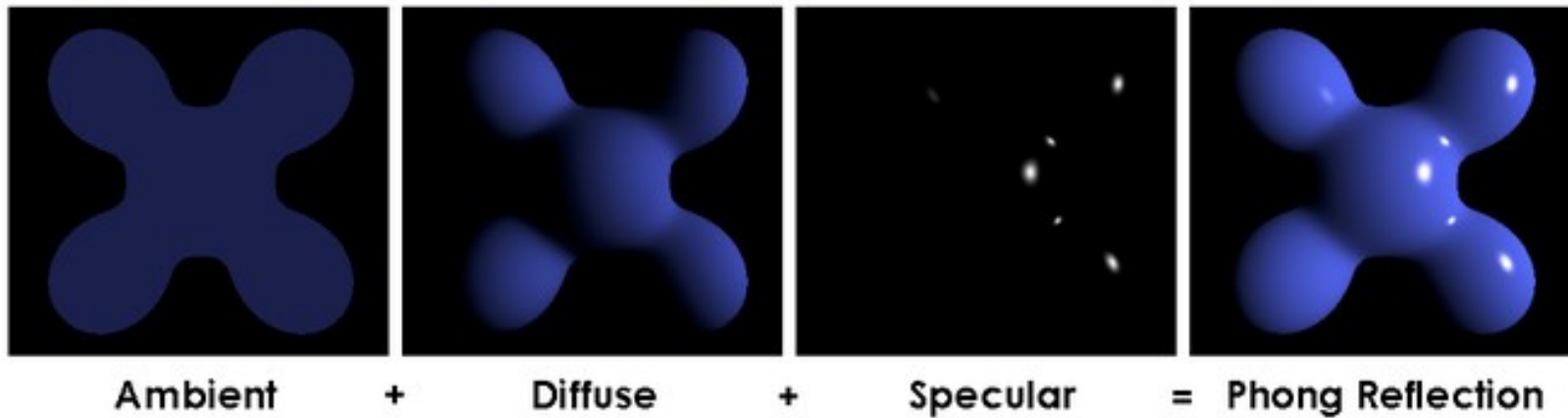


diffus

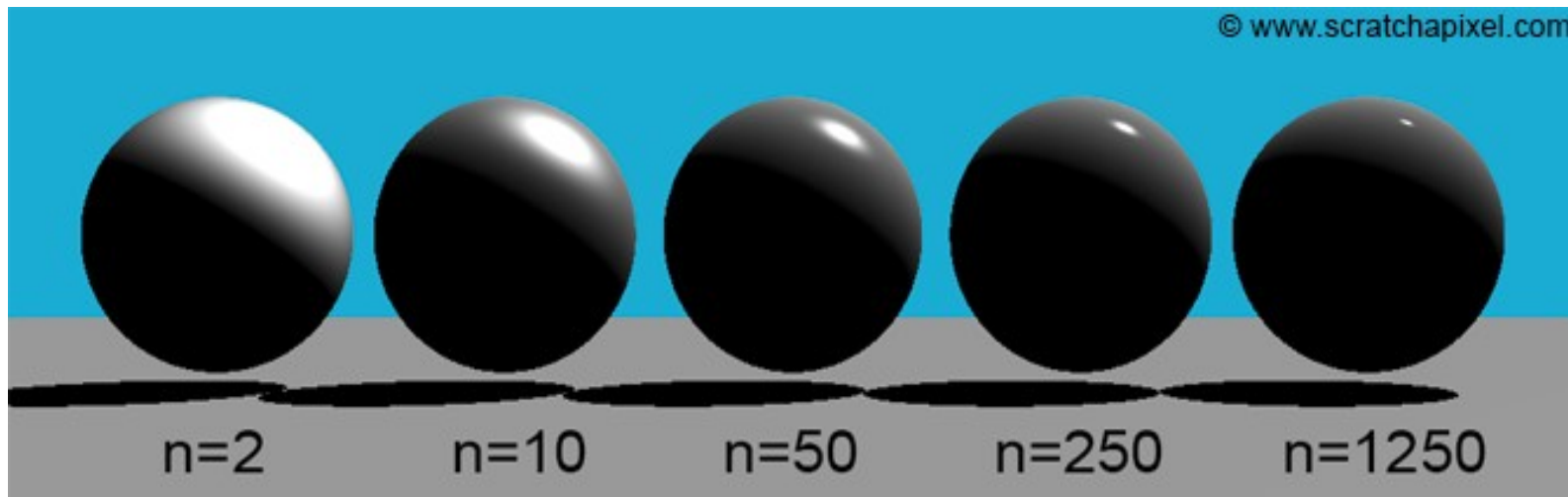
$$f_r(x, \omega_i, \omega_r)$$



# Phong Shading

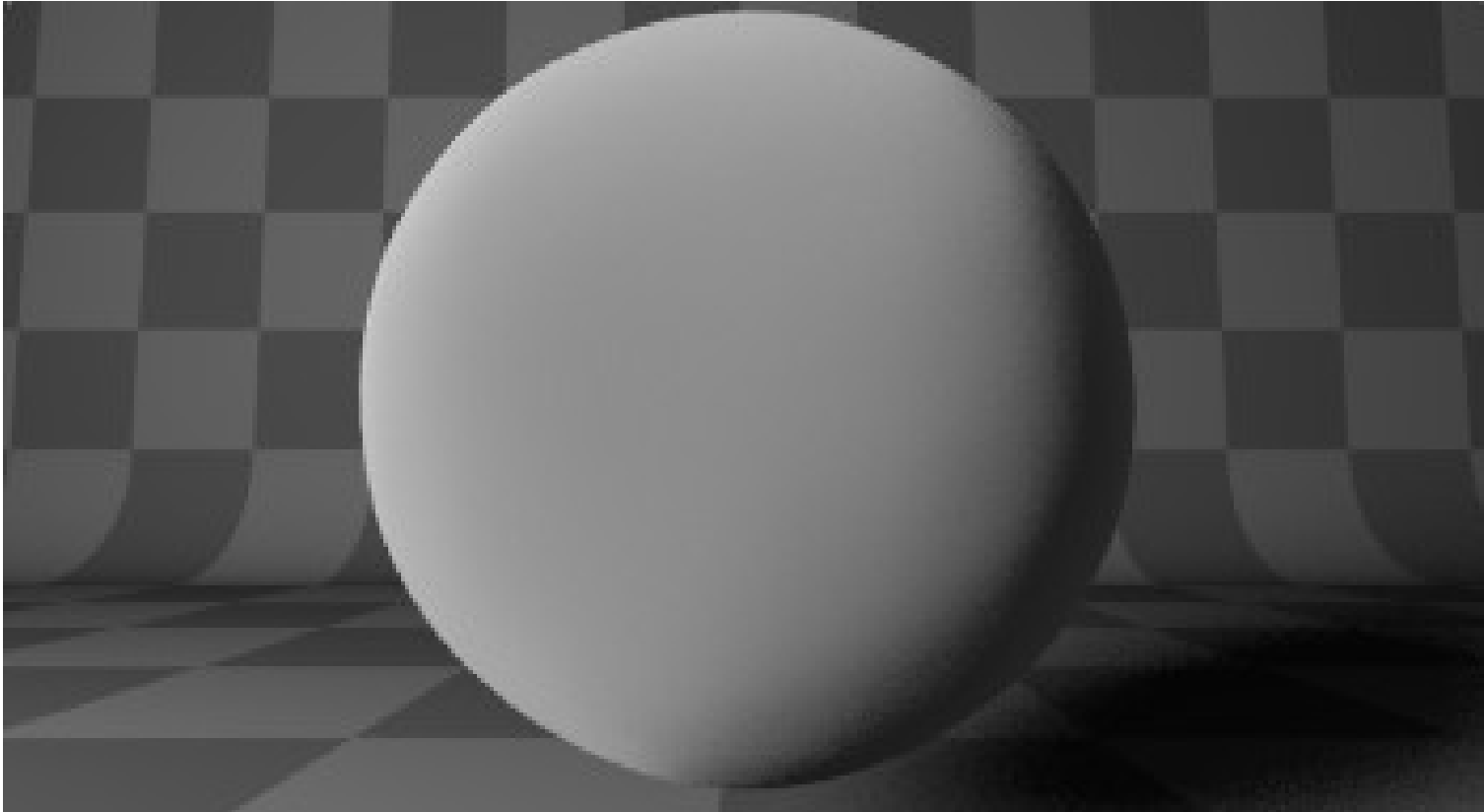


# Phong Shading

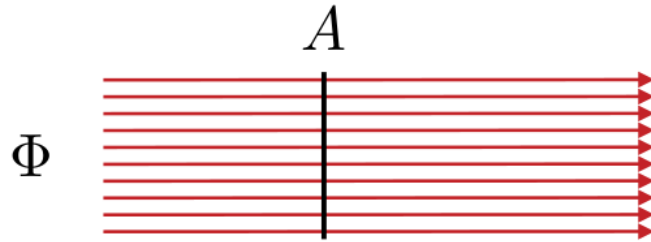




# Licht und Schatten



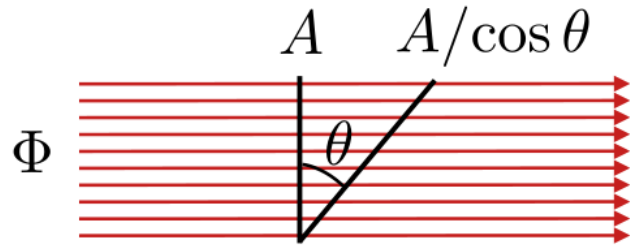
# Lambert's Cosinus Gesetz



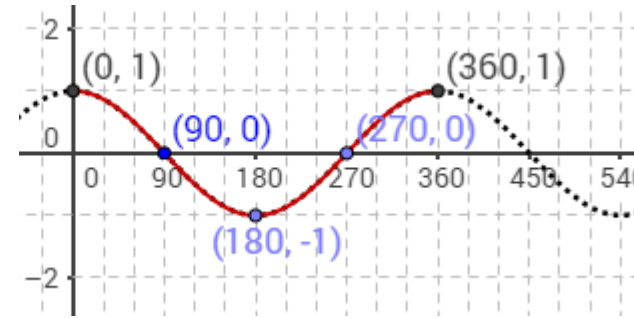
$$E = \frac{\Phi}{A}$$



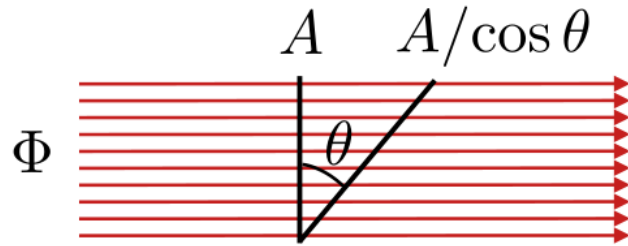
# Lambert's Cosinus Gesetz



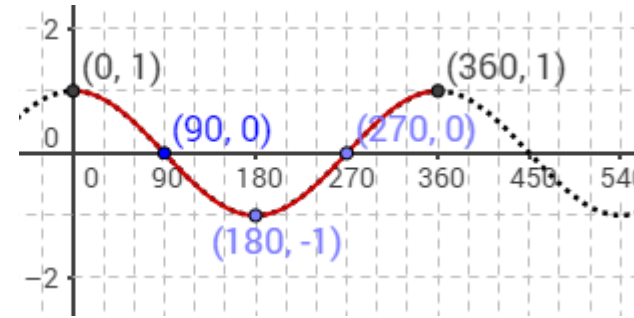
$$E = \frac{\Phi}{A/\cos \theta} = \frac{\Phi}{A} \cos \theta$$



# Lambert's Cosinus Gesetz



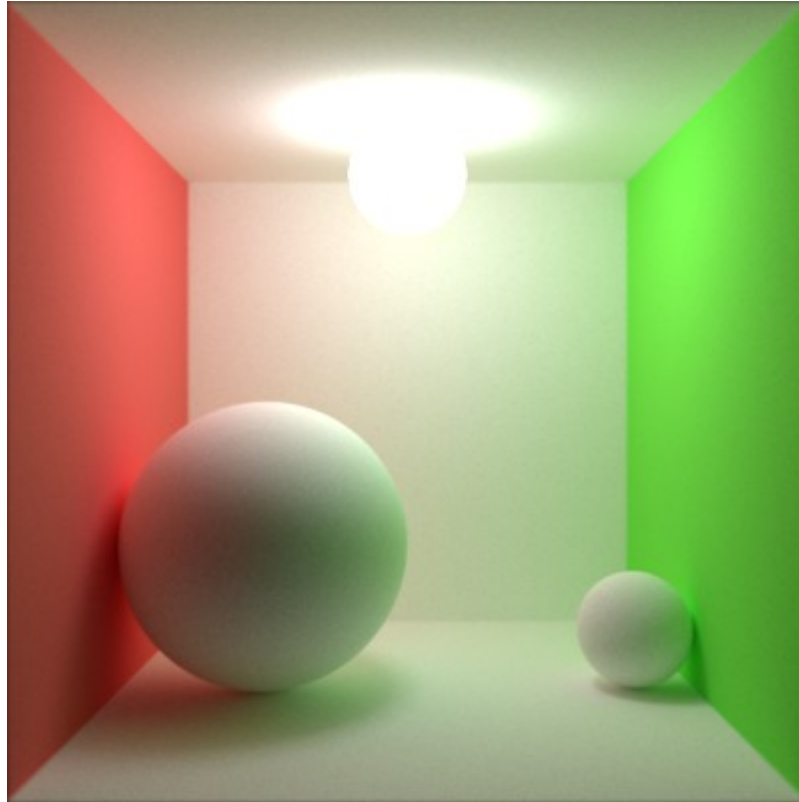
$$E = \frac{\Phi}{A/\cos \theta} = \frac{\Phi}{A} \cos \theta$$



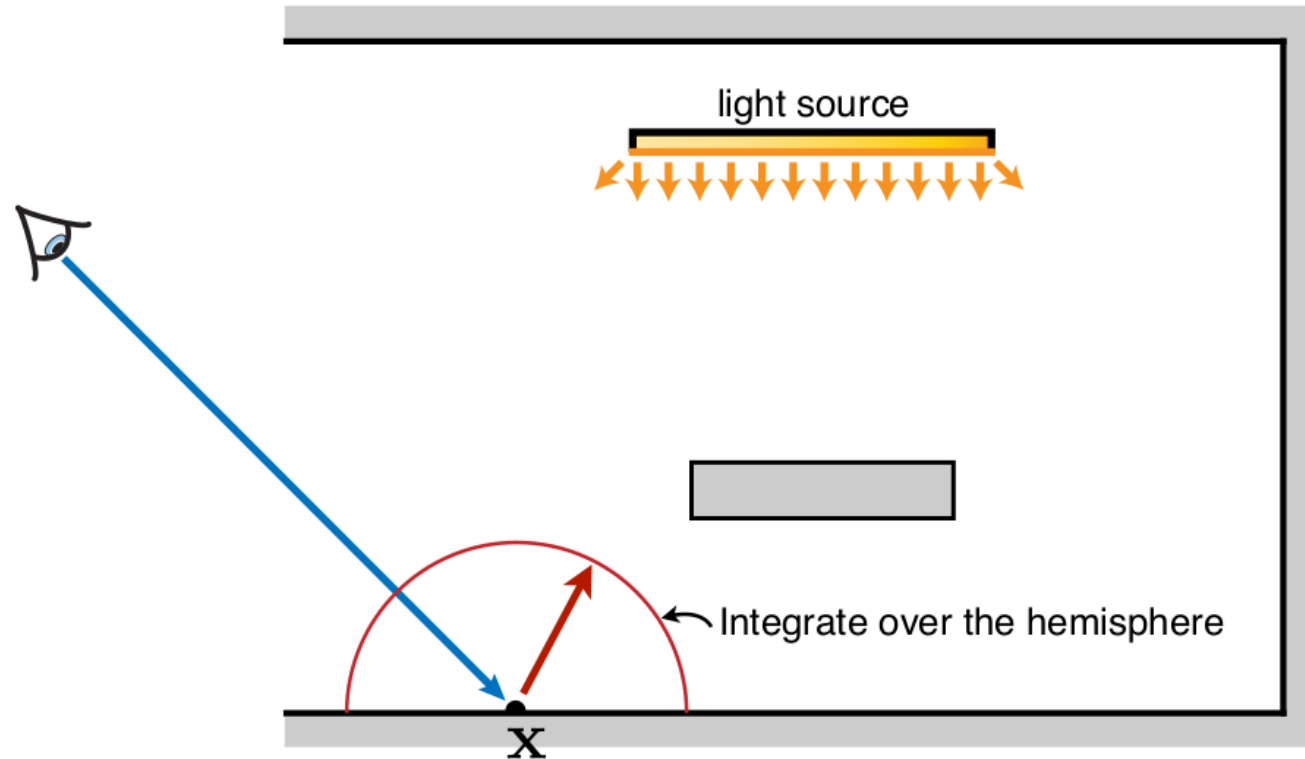
$$L_i(x, \omega_i) * \cos(\theta_i)$$



# Indirektes Licht

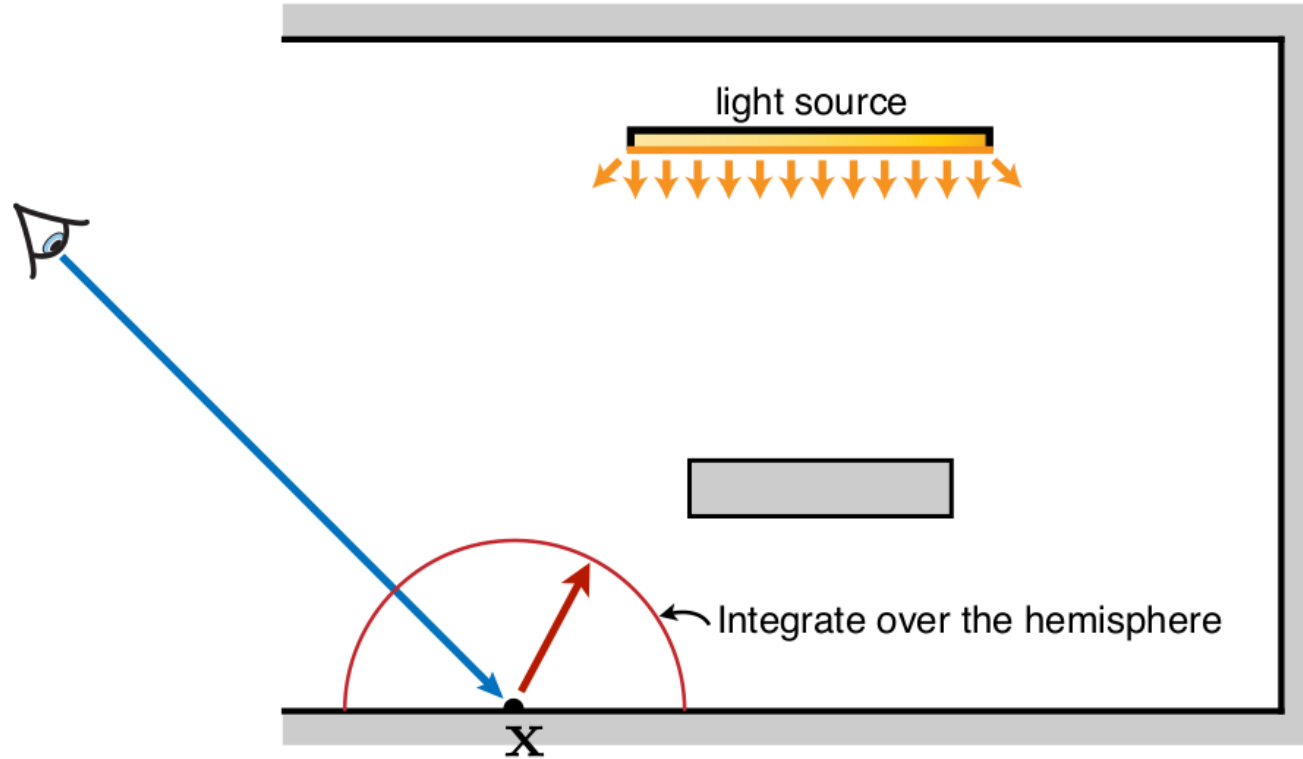


# Halbkugel





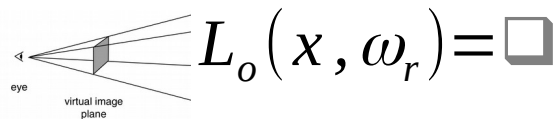
# Halbkugel



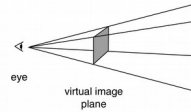
$$\int_{H^2} \square d\omega_i$$



# Rendering Equation



# Rendering Equation

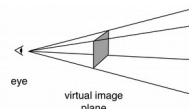


The diagram shows an eye on the left, looking through a small rectangular aperture. Several lines radiate from the eye, passing through the aperture and extending to the right. Below the aperture, the text "virtual image plane" is written. To the right of the diagram, the equation  $L_o(x, \omega_r) = L_e(x, \omega_r)$  is displayed. The right-hand side of the equation,  $L_e(x, \omega_r)$ , is enclosed in a yellow rectangular box.

$$L_o(x, \omega_r) = L_e(x, \omega_r)$$



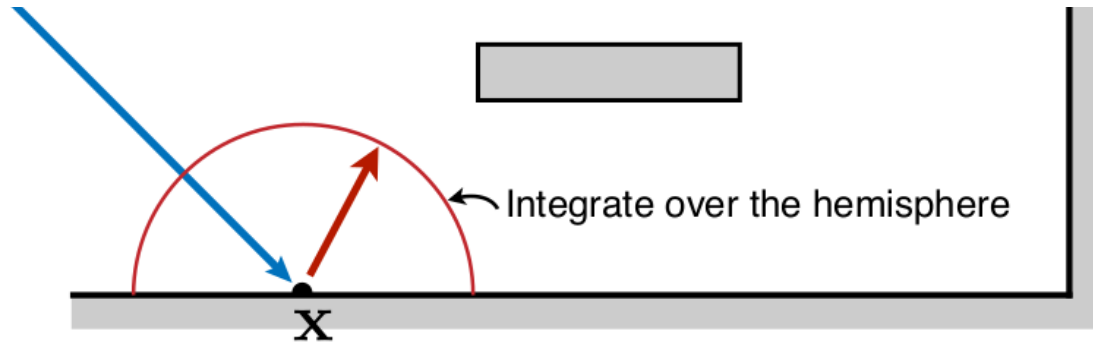
# Rendering Equation



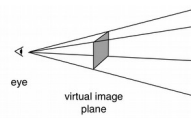
eye  
virtual image  
plane

$$L_o(x, \omega_r) = L_e(x, \omega_r) + \int_{H^2}$$

$$d\omega_i$$

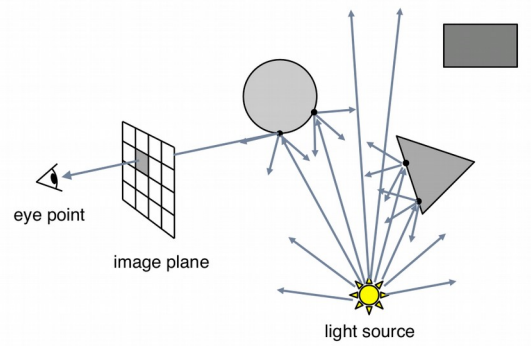


# Rendering Equation

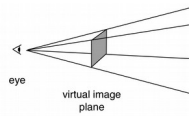


$$L_o(x, \omega_r) = L_e(x, \omega_r) + \int_{H^2} L_i(x, \omega_i) \cos(\theta_i) d\omega_i$$

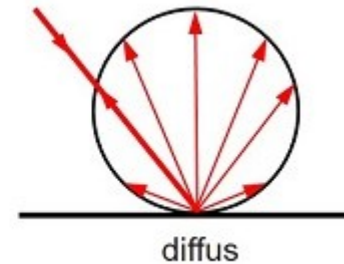
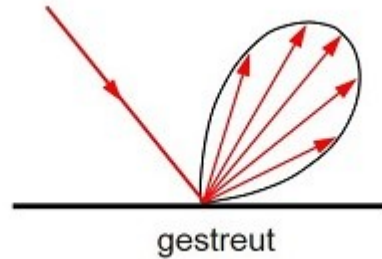
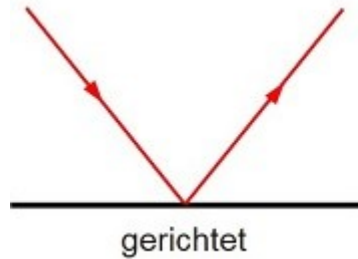
$d\omega_i$



# Rendering Equation

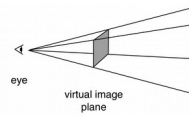


$$L_o(x, \omega_r) = L_e(x, \omega_r) + \int_{H^2} L_i(x, \omega_i) * \cos(\theta_i) * f_r(x, \omega_i, \omega_r) d\omega_i$$





# Rendering Equation



The diagram shows an eye on the left, looking at a virtual image plane. Several rays originate from the eye and pass through the plane, illustrating the concept of a virtual image plane in computer graphics.

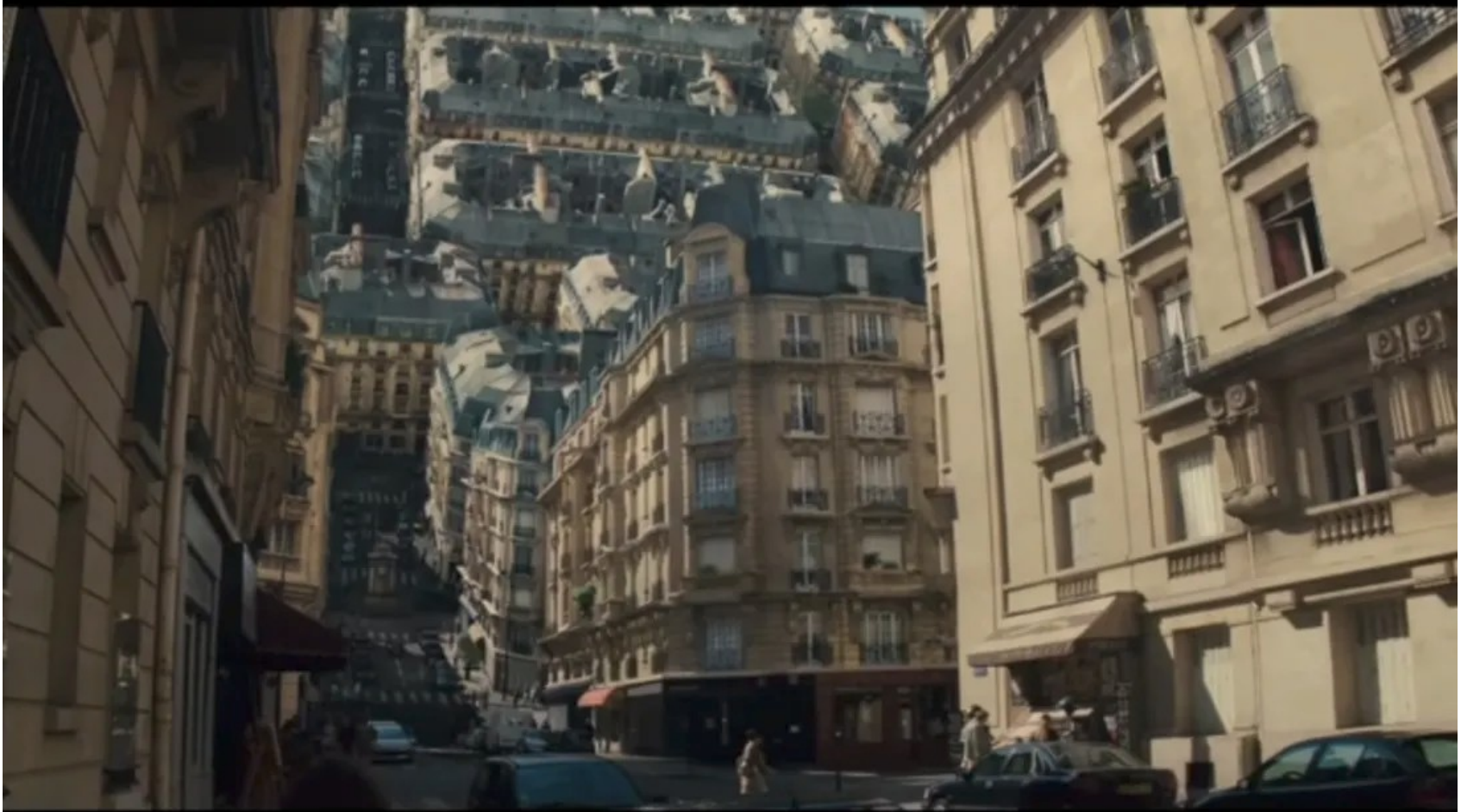
$$L_o(x, \omega_r) = L_e(x, \omega_r) + \int_{H^2} f_r(x, \omega_i, \omega_r) * L_i(x, \omega_i) * \cos(\theta_i) d\omega_i$$



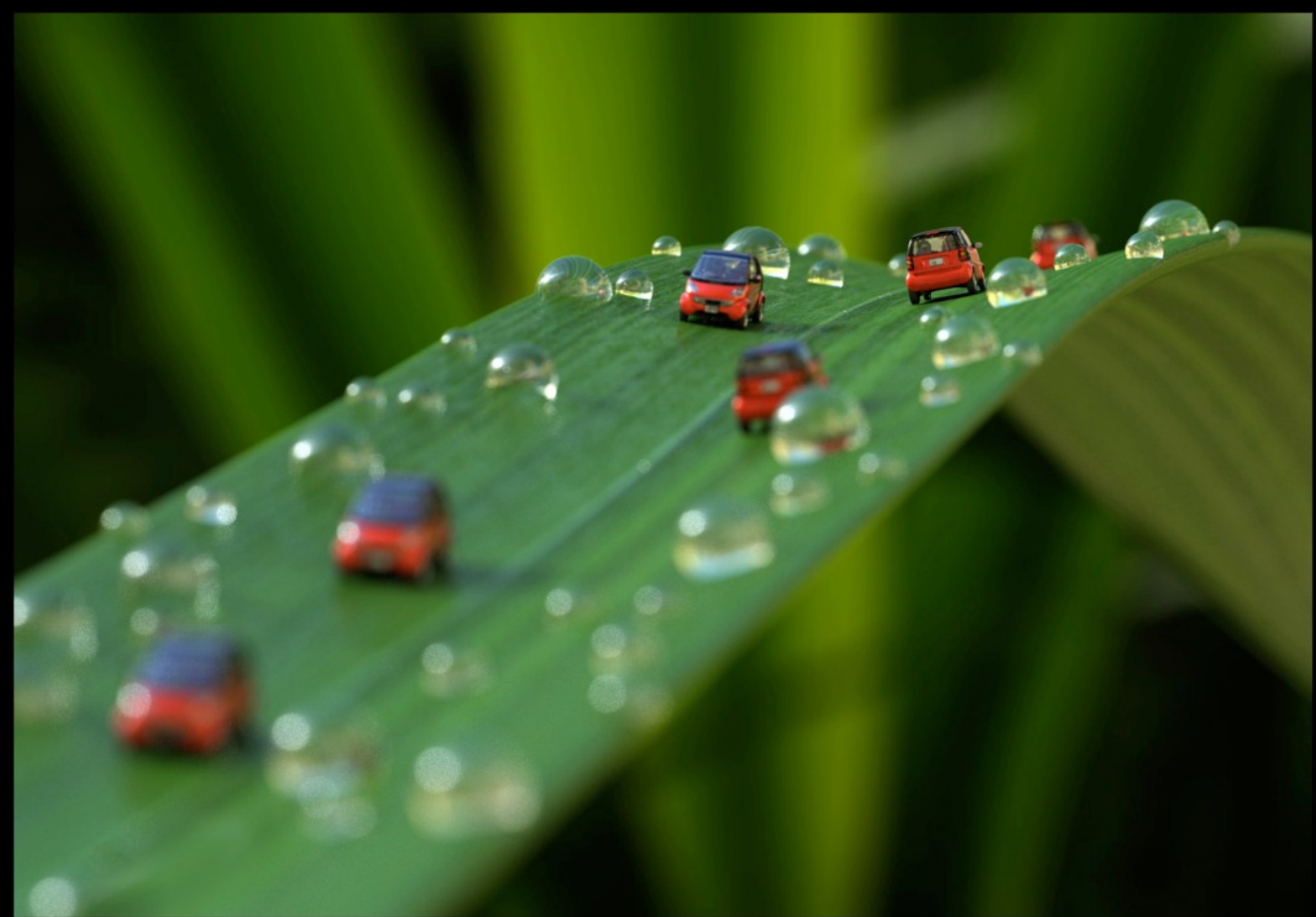
# Ergebnisse



# Ergebnisse

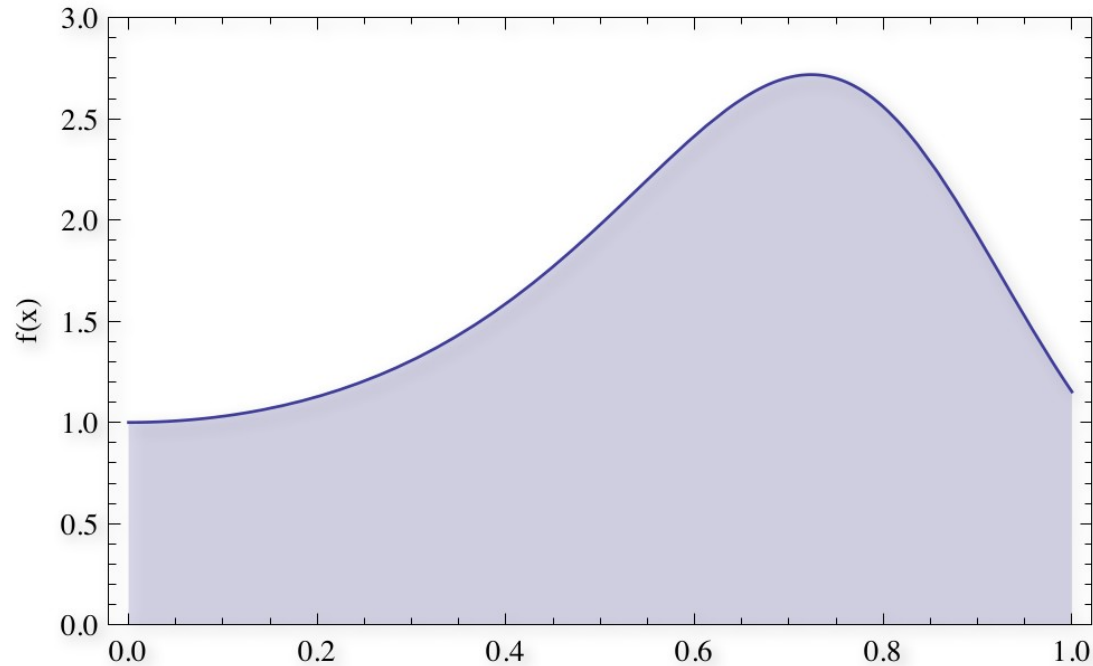


# Ergebnisse



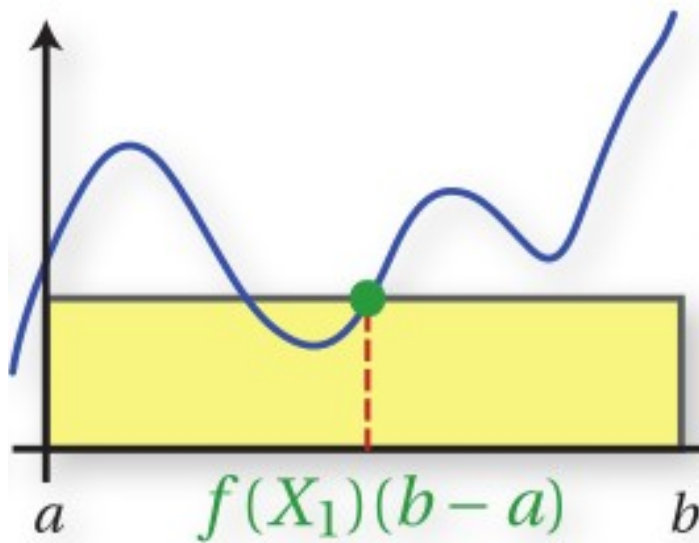
# Integrale

$$F = \int_0^1 e^{\sin(3x^2)} dx$$

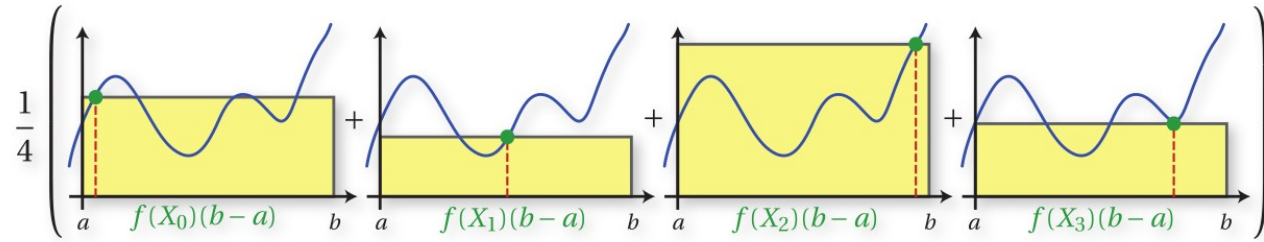




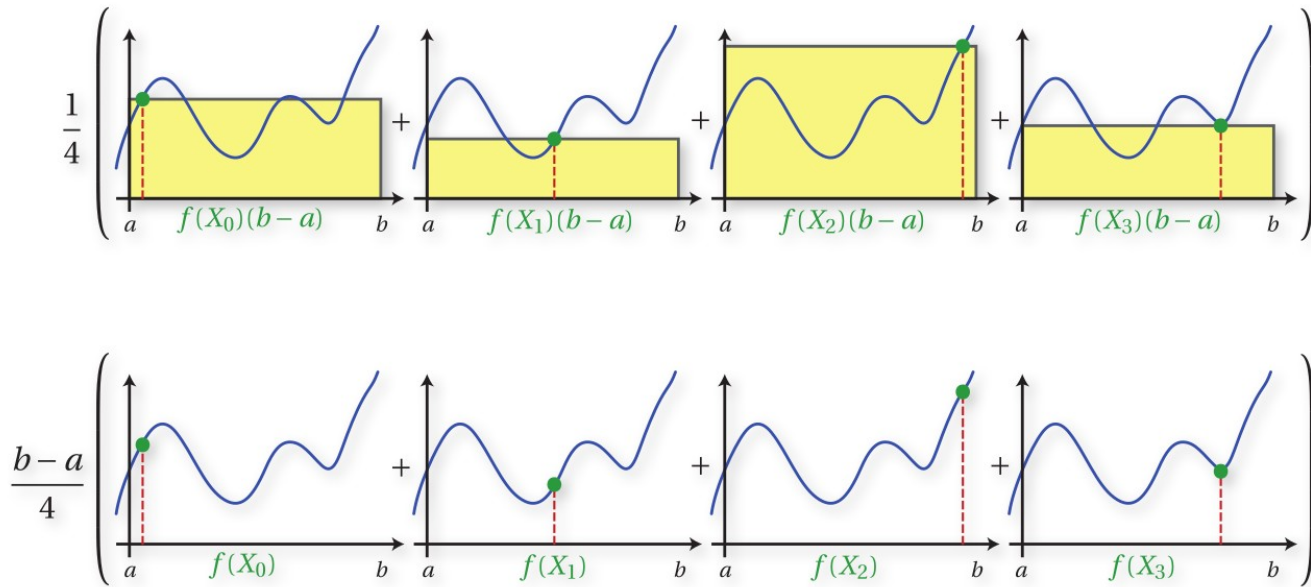
# Monte Carlo



# Monte Carlo

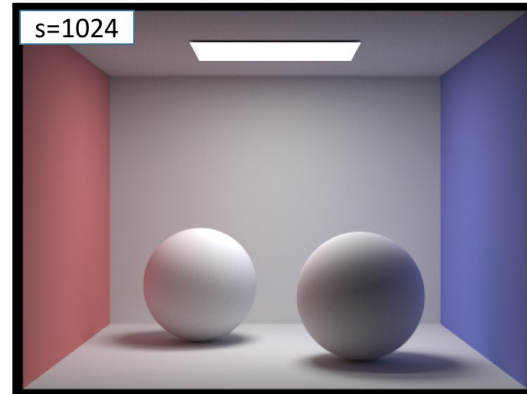
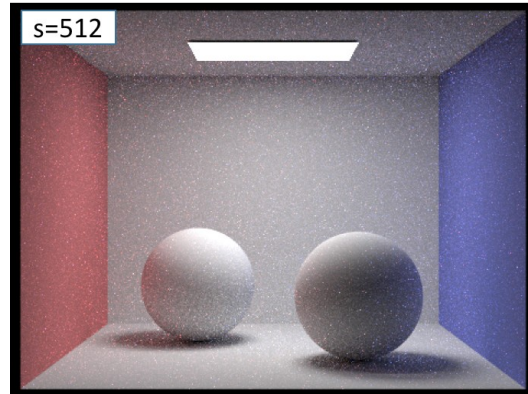
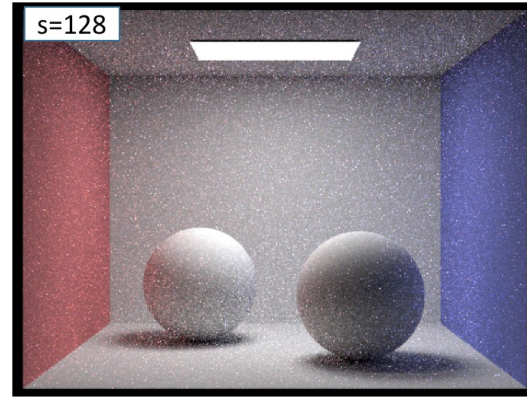
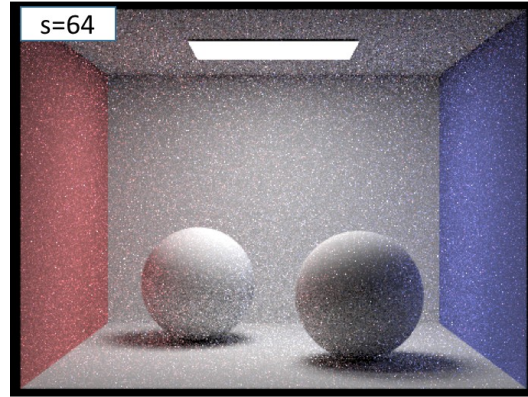


# Monte Carlo

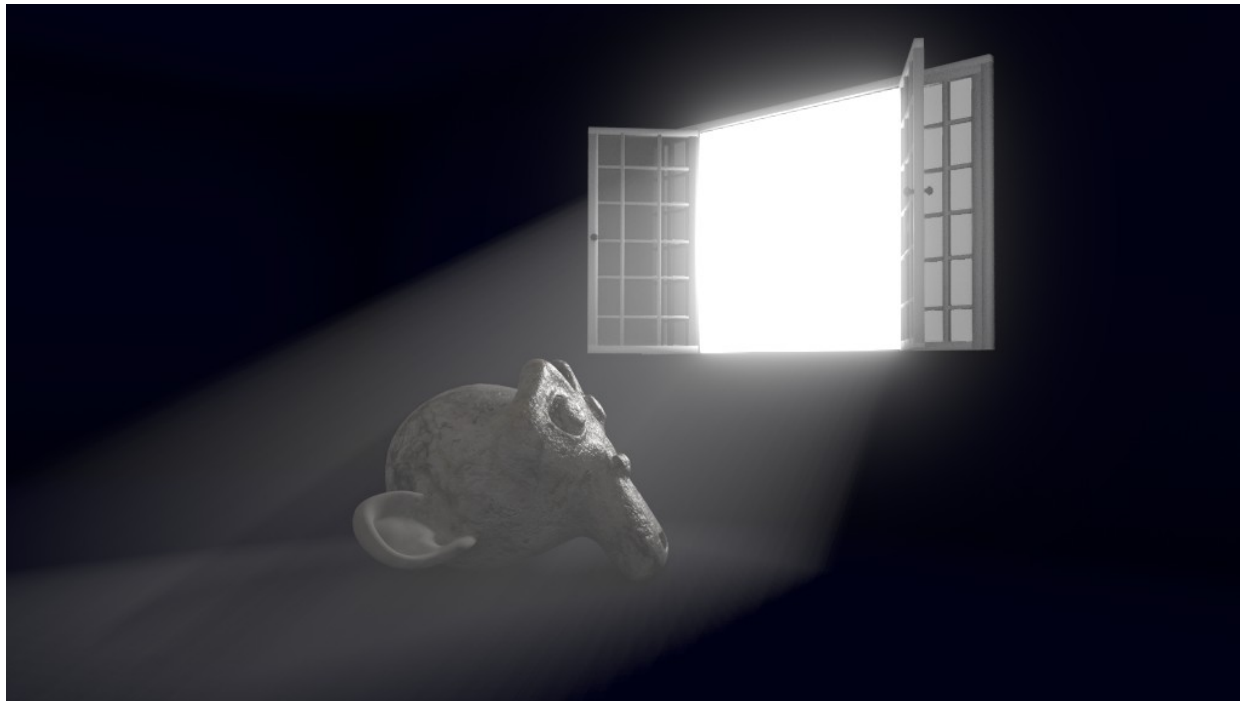




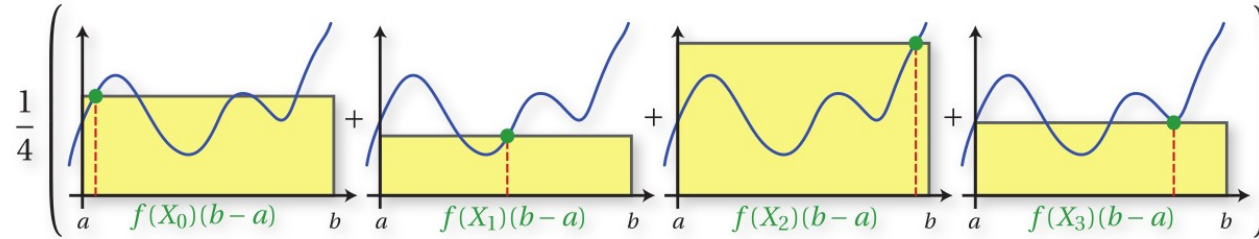
# Monte Carlo



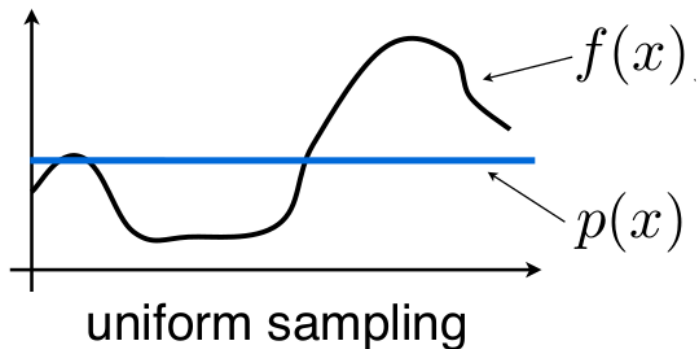
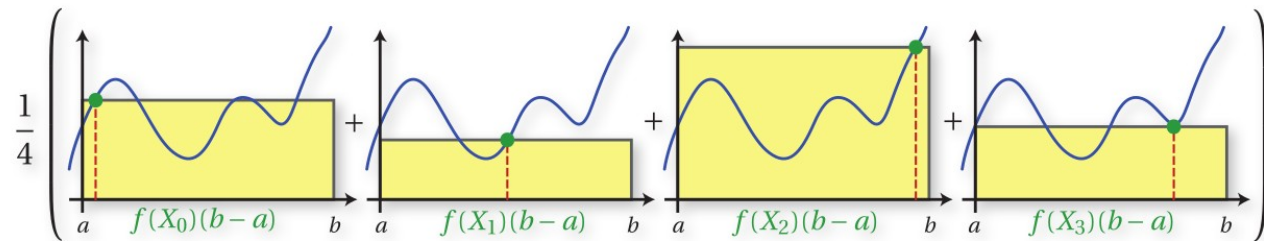
# Importance Sampling



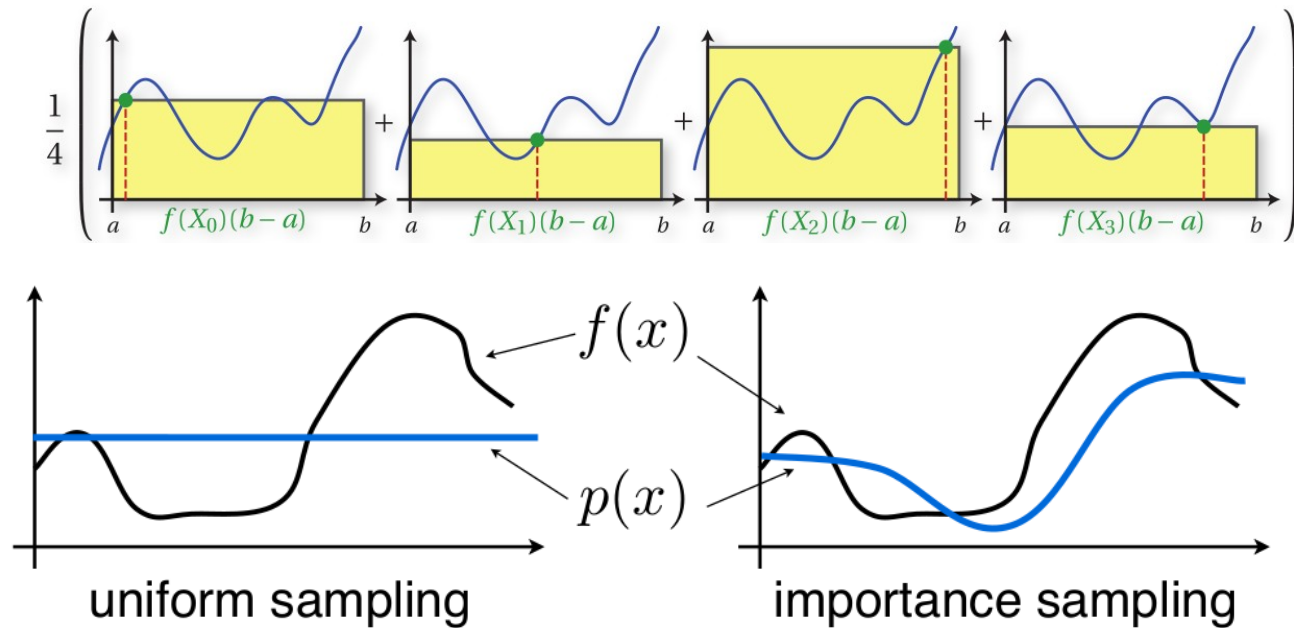
# Importance Sampling



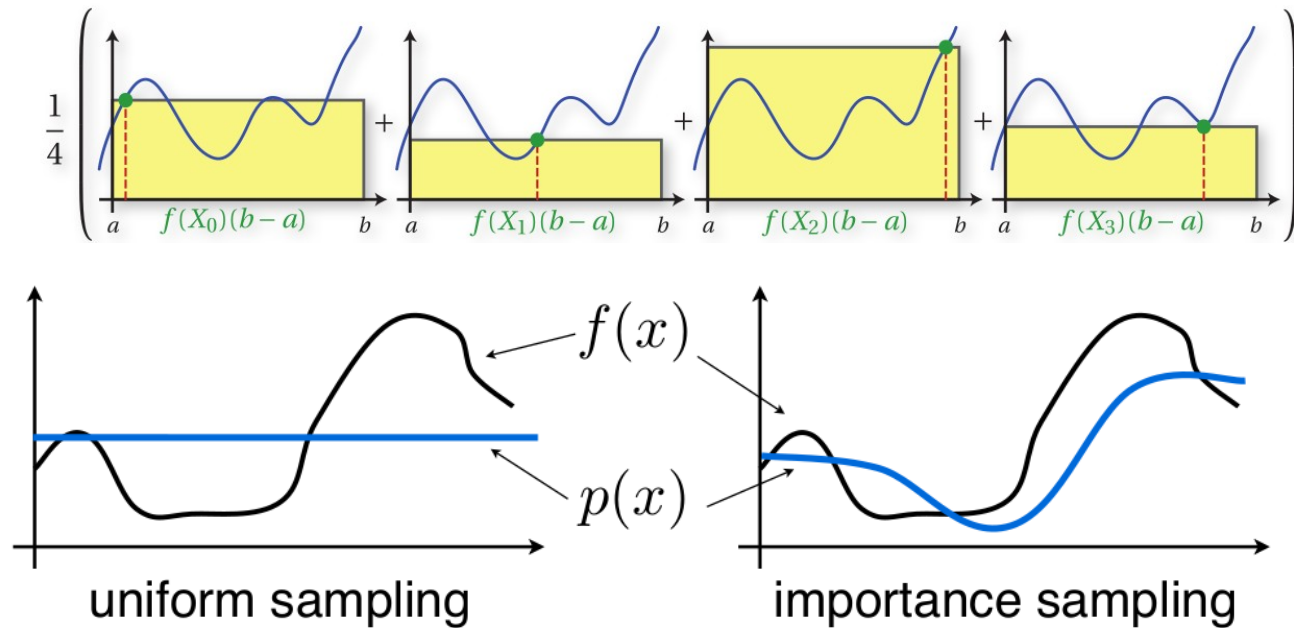
# Importance Sampling



# Importance Sampling



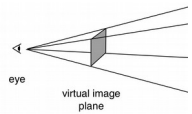
# Importance Sampling



$$F_N = \frac{1}{N} \sum_{i=1}^N \frac{f(X_i)}{p(X_i)}$$



# Woher kommt f?



The diagram shows an eye on the left looking at a virtual image plane. Light rays from the eye converge at a point on the plane, which is labeled 'virtual image plane'.

$$L_o(x, \omega_r) = L_e(x, \omega_r) + \int_{H^2} f_r(x, \omega_i, \omega_r) * L_i(x, \omega_i) * \cos(\theta_i) d\omega_i$$



# Woher kommt f?

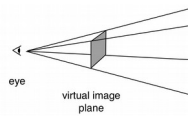
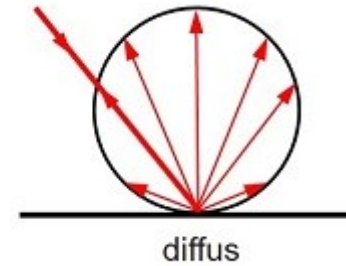
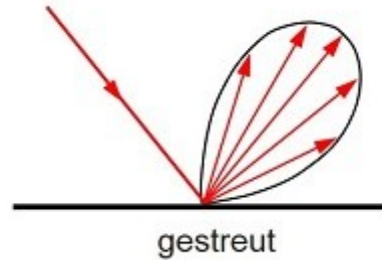
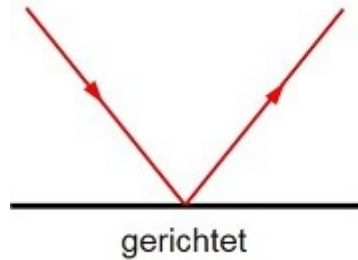


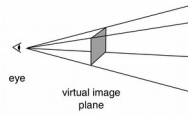
Diagram illustrating the geometry of light transport. An eye is shown on the left, looking at a virtual image plane. Light rays are shown originating from the image plane and entering the eye.

$$L_o(x, \omega_r) = L_e(x, \omega_r) + \int_{H^2} f_r(x, \omega_i, \omega_r) * L_i(x, \omega_i) * \cos(\theta_i) d\omega_i$$

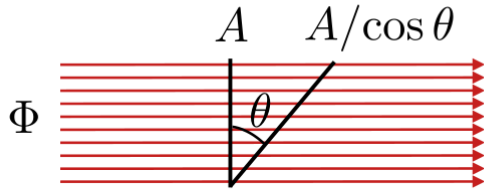




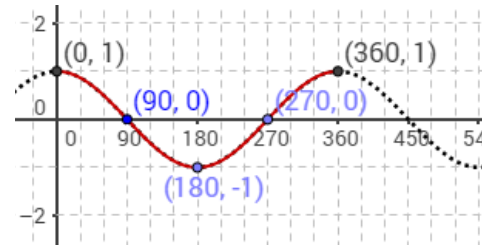
# Woher kommt f?



$$L_o(x, \omega_r) = L_e(x, \omega_r) + \int_{H^2} f_r(x, \omega_i, \omega_r) * L_i(x, \omega_i) * \cos(\theta_i) d\omega_i$$



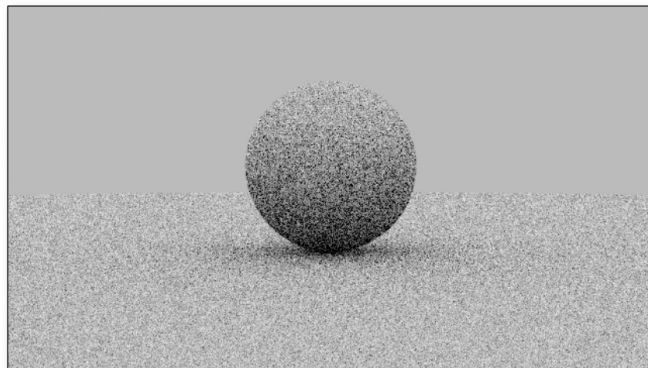
$$E = \frac{\Phi}{A/\cos \theta} = \frac{\Phi}{A} \cos \theta$$



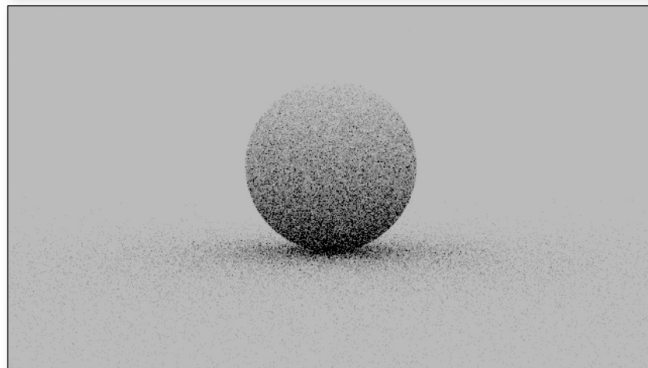
# Importance Sampling

**Uniform  
Hemispherical  
Sampling**

4 samples



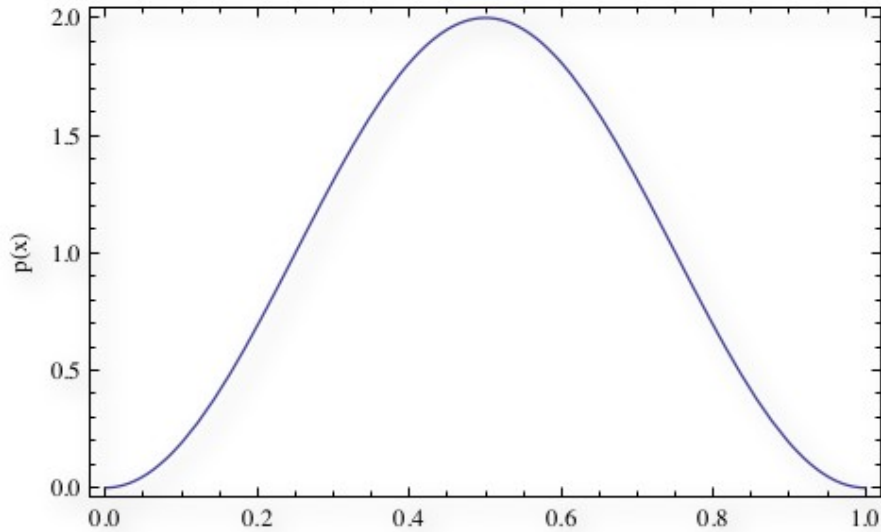
**Cosine-weighted  
Hemispherical  
Sampling**



Ich habe mein  $p(x)$ . Wie  
Generiere ich Samples?



# PDF

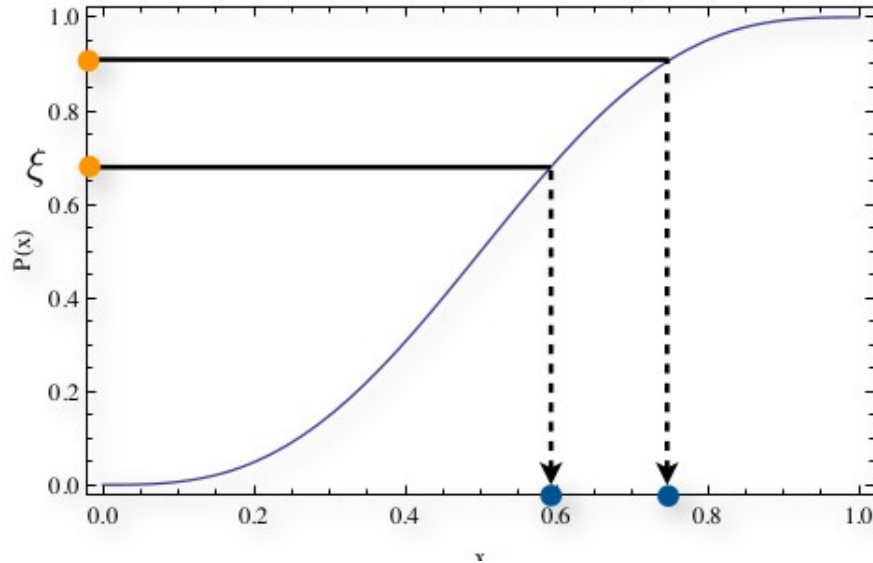


Probability Distribution Function

$$p(x) = P[\xi=x]$$



# CDF

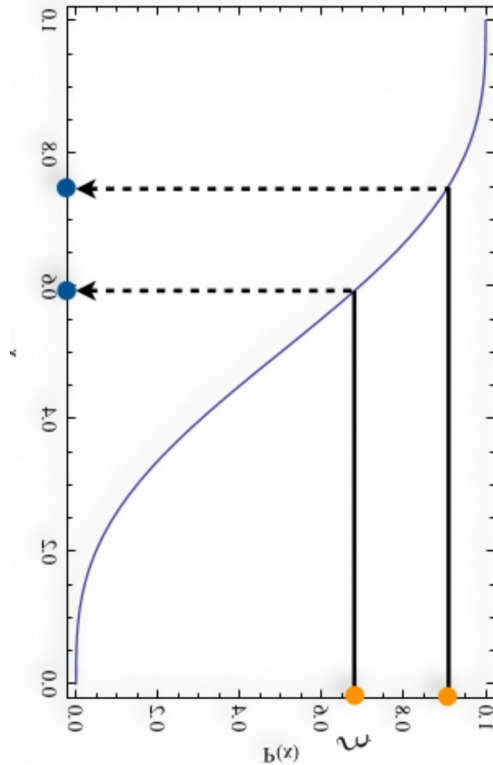


Cumulative Distribution Function

$$P(x) = P[\xi \leq x] \\ = \int_0^x p(x') dx'$$



# CDF<sup>-1</sup>



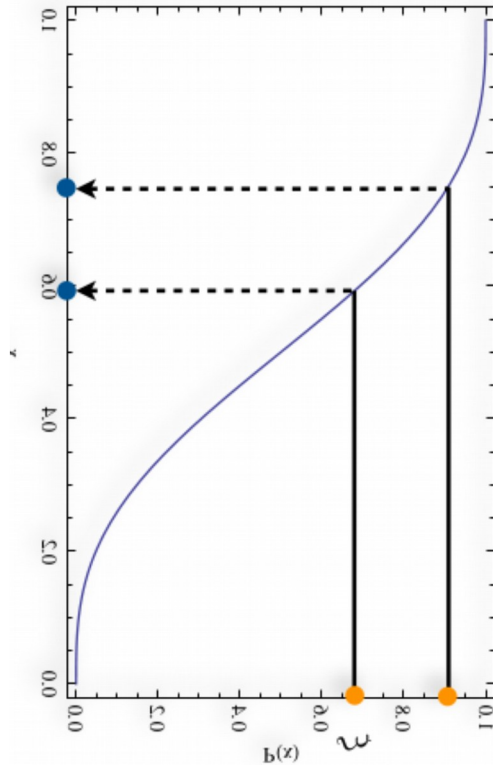
## Invserse $P^{-1}(\xi)$

Generiere  $\xi$  uniform zufällig

Sample  $X_i = P^{-1}(\xi)$



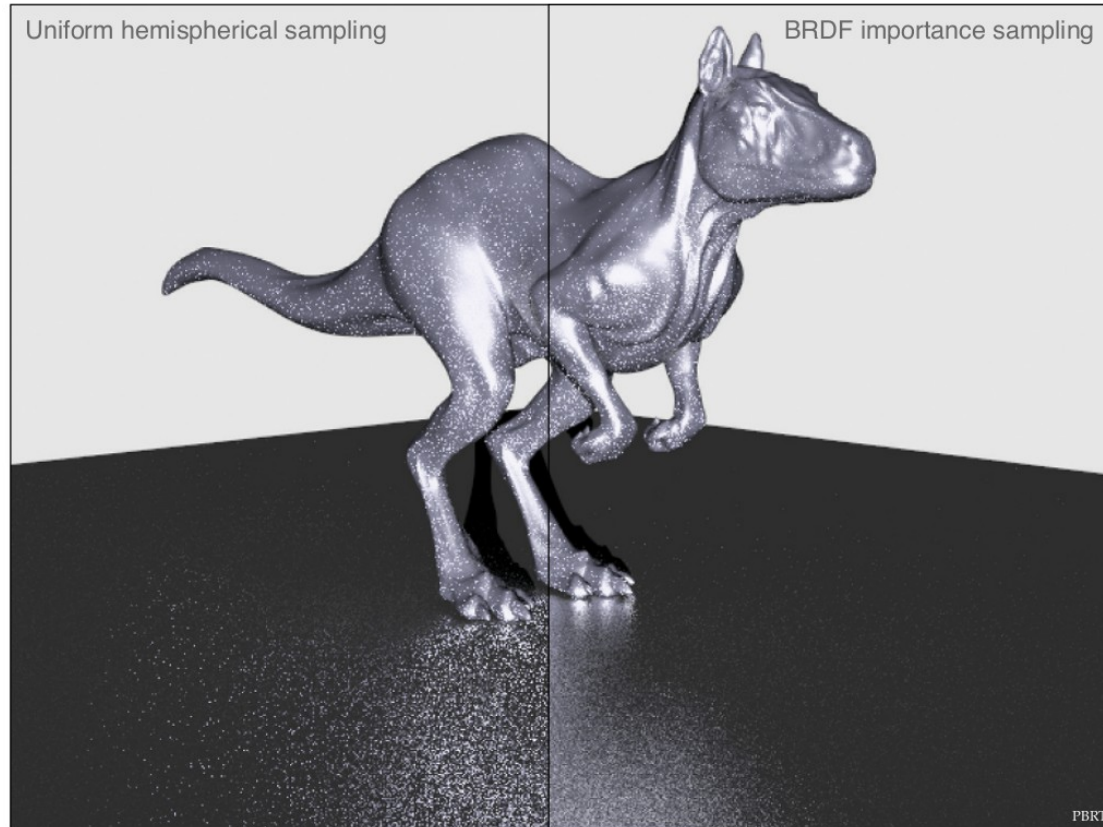
# CDF<sup>-1</sup>



Wahrscheinlichkeit von  $X_i$ :  
 $p(X_i)$



# Importance Sampling

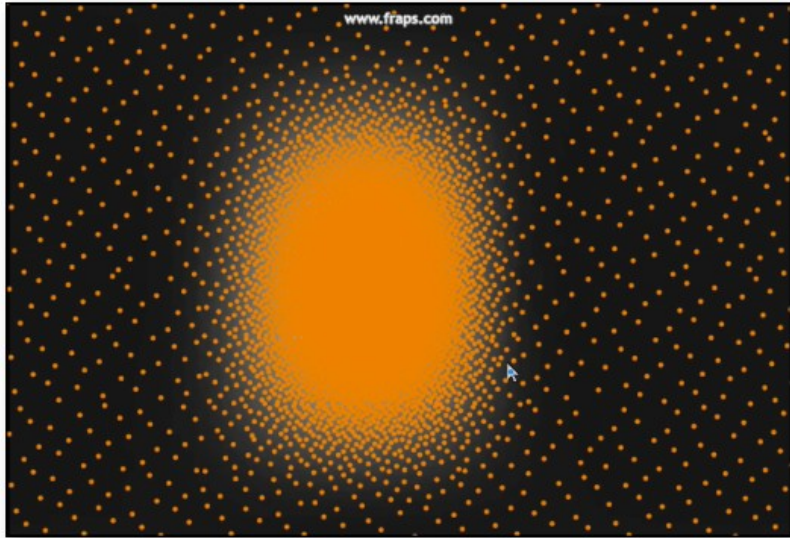




# Environment Map

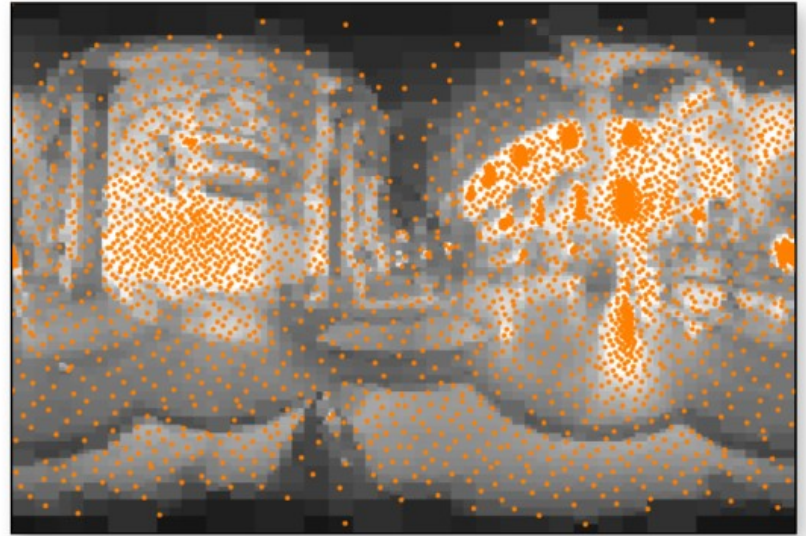


# Importance Sampling



BRDF

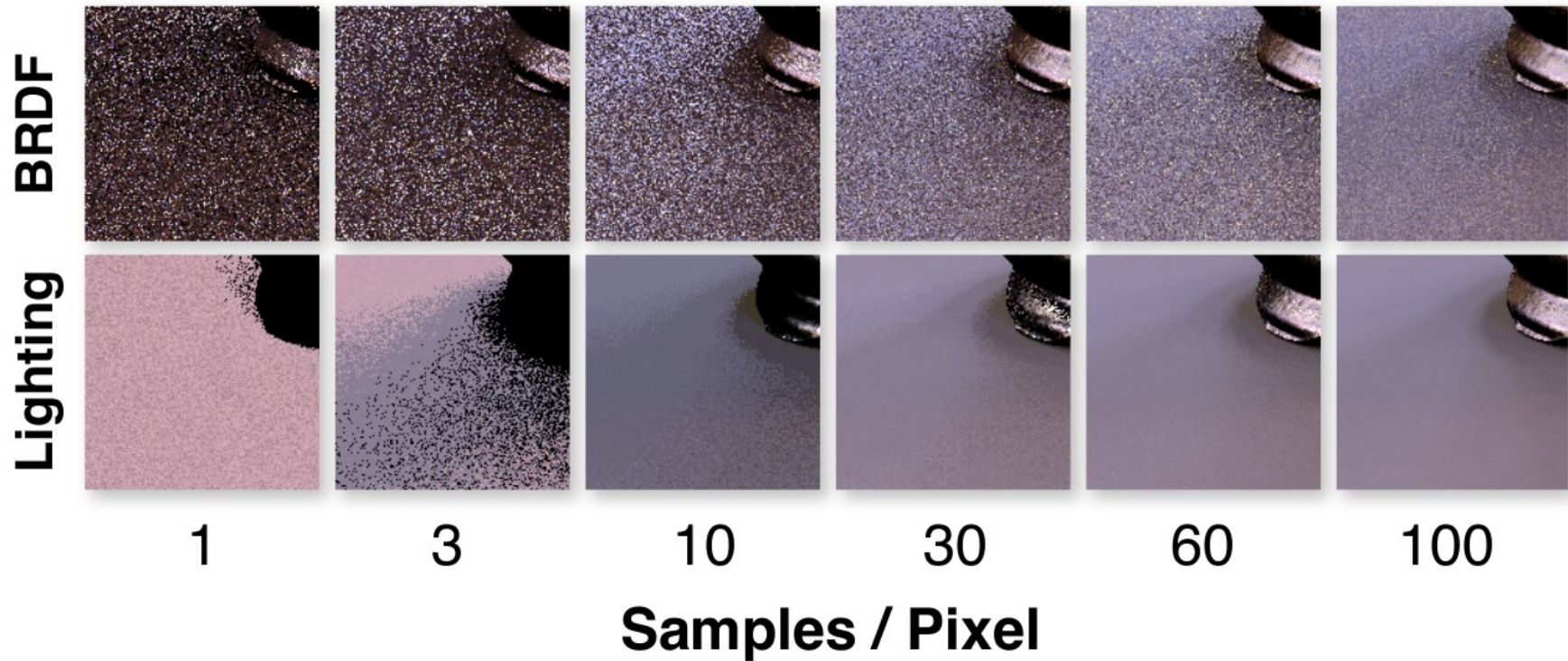
or



Lighting



# Importance Sampling





# Ergebnisse



# Ergebnisse





# Ergebnisse

