Practical multiple scattering in rough surface

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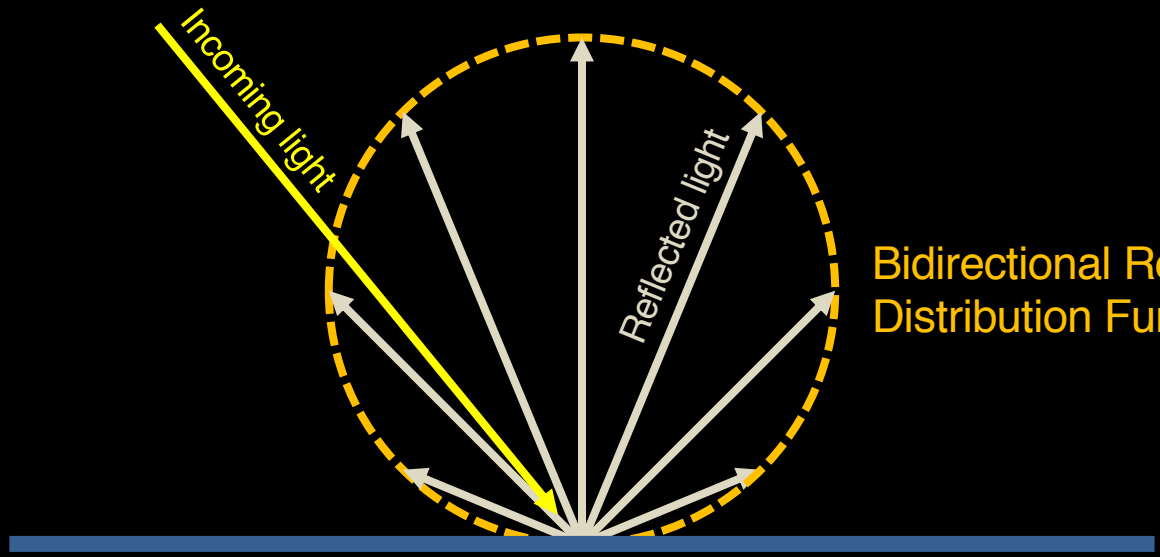
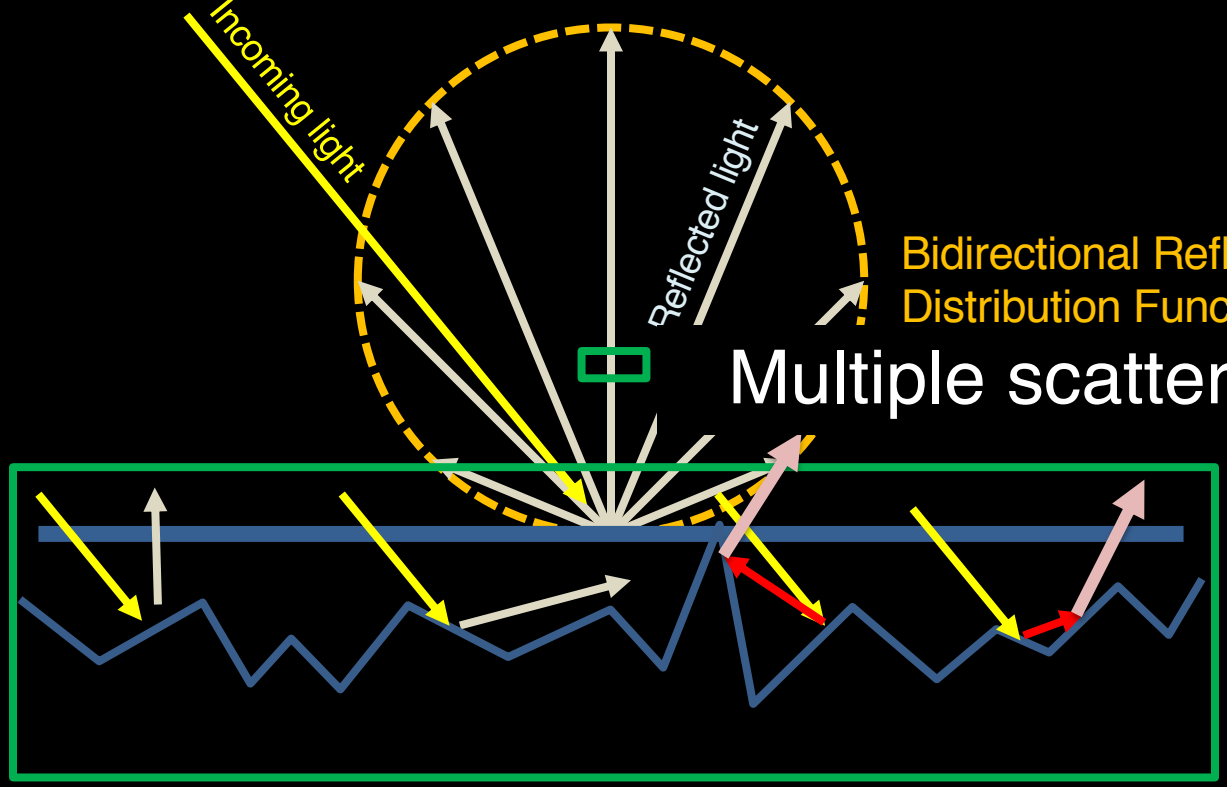
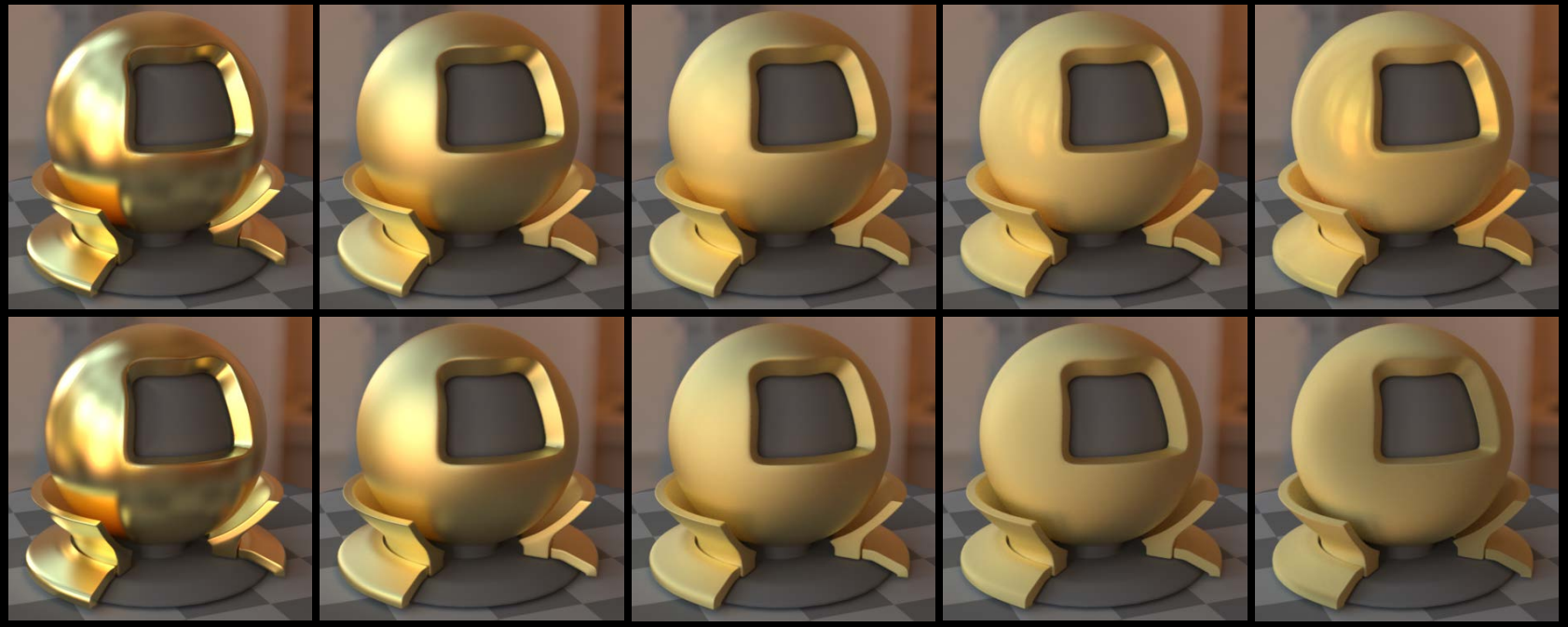


Bidirectional Reflection Distribution Function (BRDF)

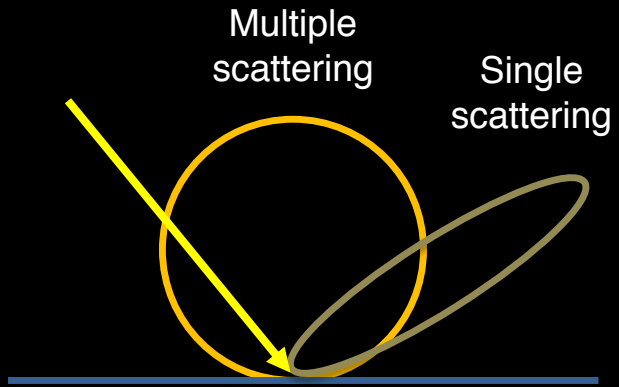

Incoming light
Reflected light
Bidirectional Reflection
Distribution Function (BRDF)
Multiple scattering

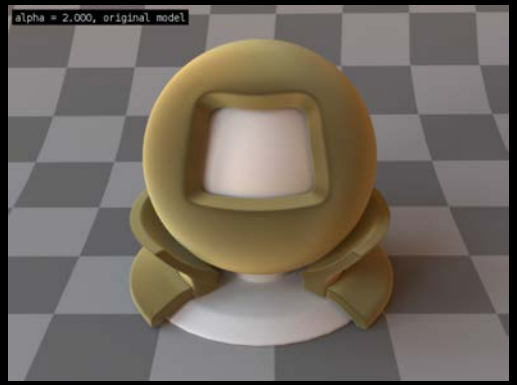
OUR WORK


Our model
The current microfacet model
Roughness increase

RELATED WORK: MULTIPLE SCATTERING

- Hiring the **pseudo-diffuse** term
  - Kelemen and Szimary-Kalos (2001)
  - Jakob, d'Eon, Jakob, and Marschner (2014)
  - No coupling with microgeometry



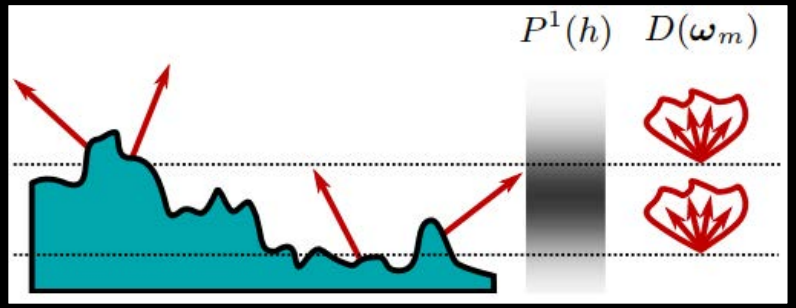


Single scattering

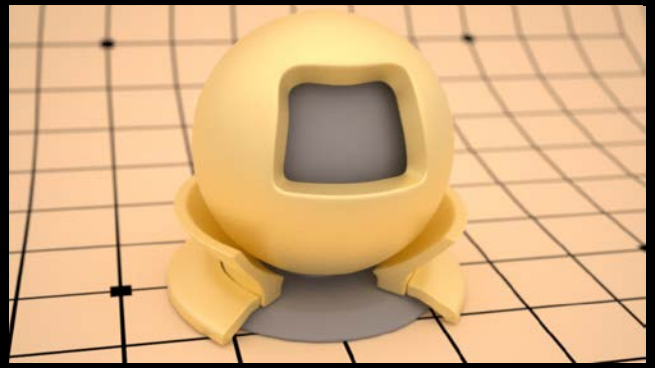
Multiple scattering

RELATED WORK: MULTIPLE SCATTERING

- Traveling in microgeometry
  - Heitz, Hanika, d'Eon, and Dachsbacher (2016)
  - Good agreement with the Gaussian surface
  - Stochastic approach



Smith model



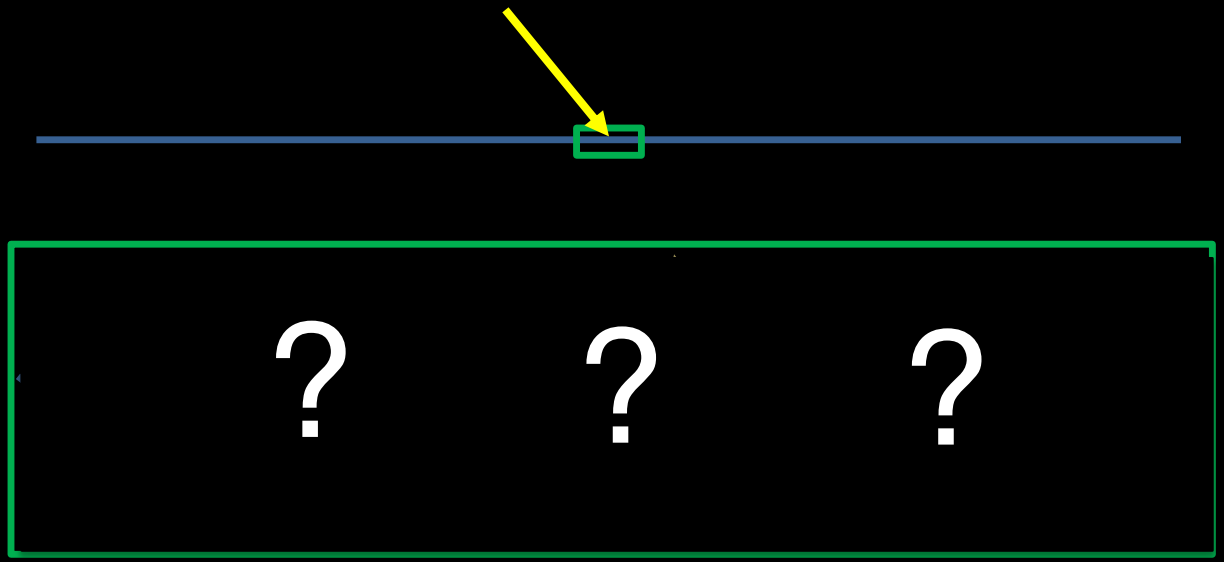
Multiple scattering

OUR MOTIVATION

No analytic model exists for multiple scattering.

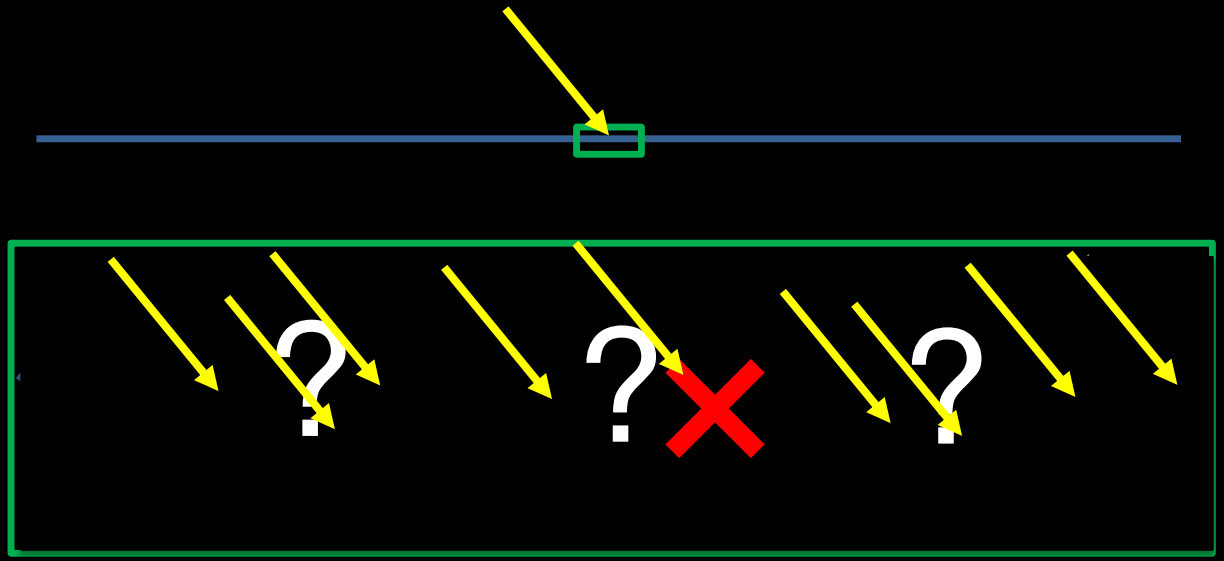
CHALLENGES

- No explicit microgeometry



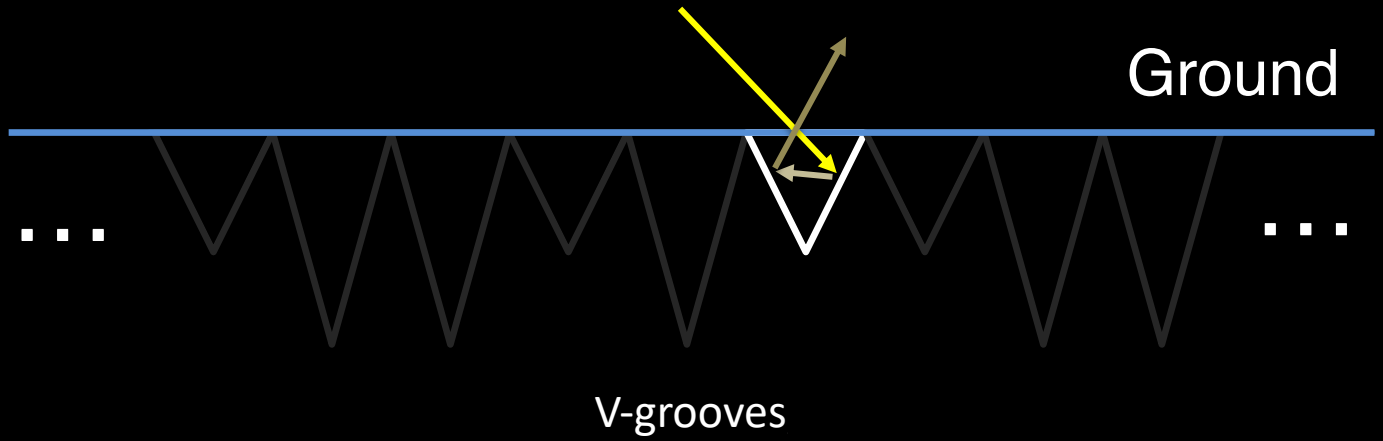
CHALLENGES

- Visibility test & complex path space

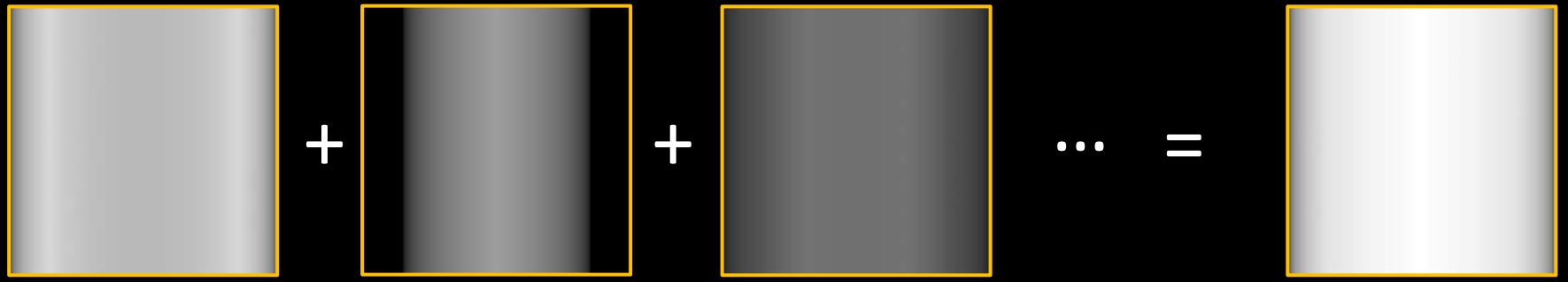


V-GROOVE WORLD

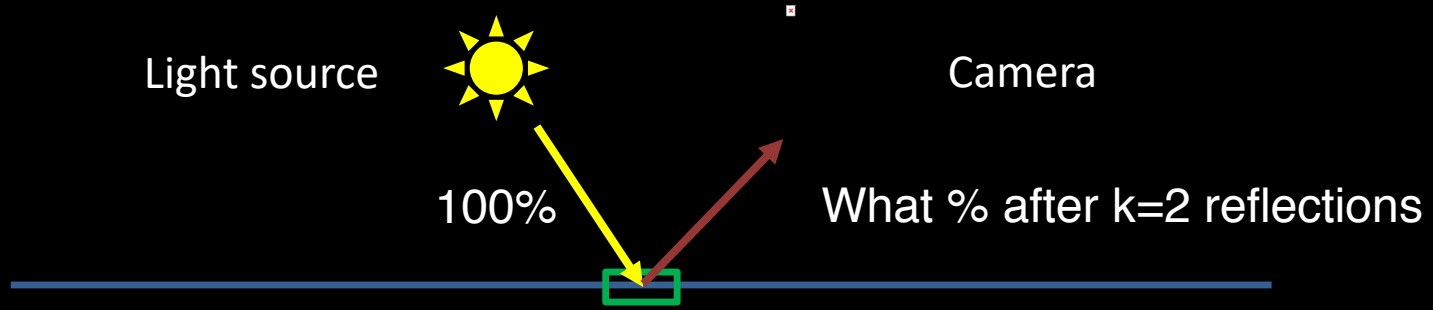
Microgeometry = A set of 3D V-grooves

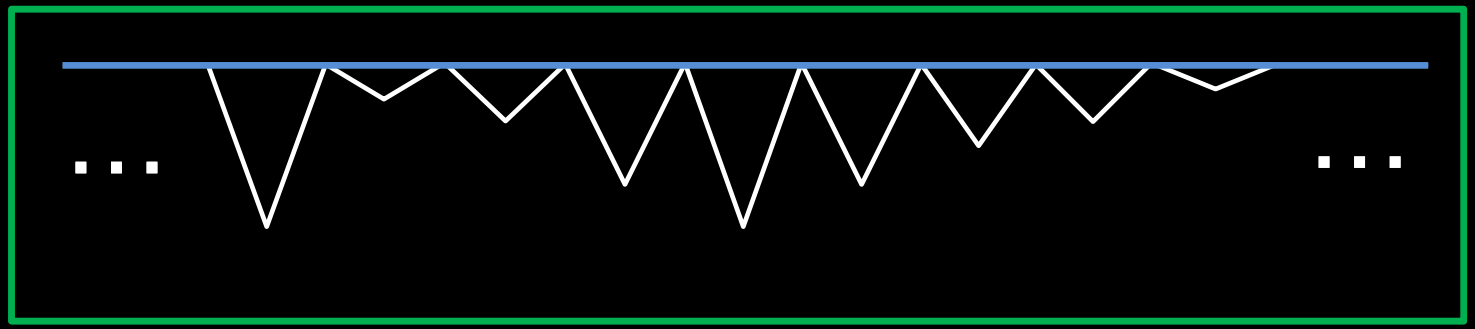


K-REFLECTION BRDF

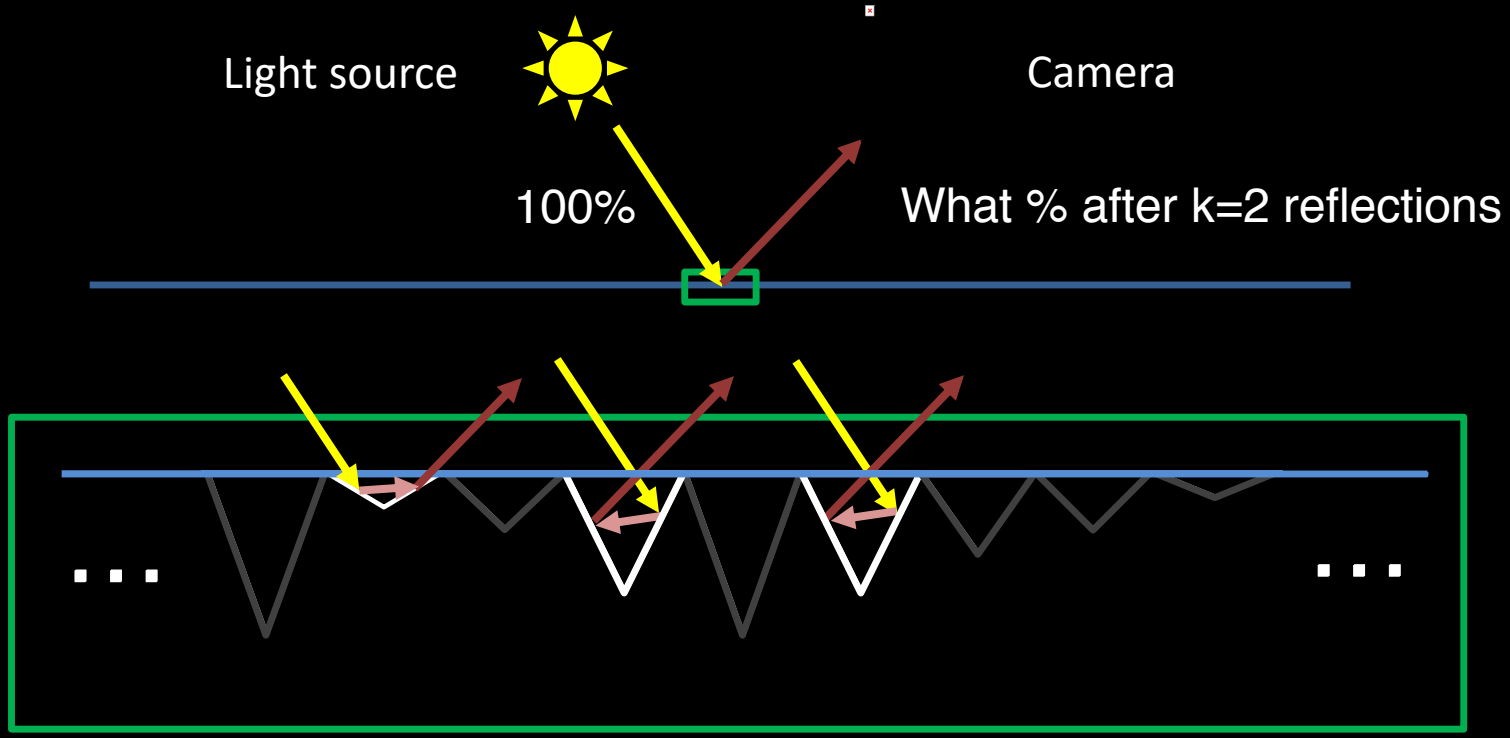


K-REFLECTION BRDF EVALUATION

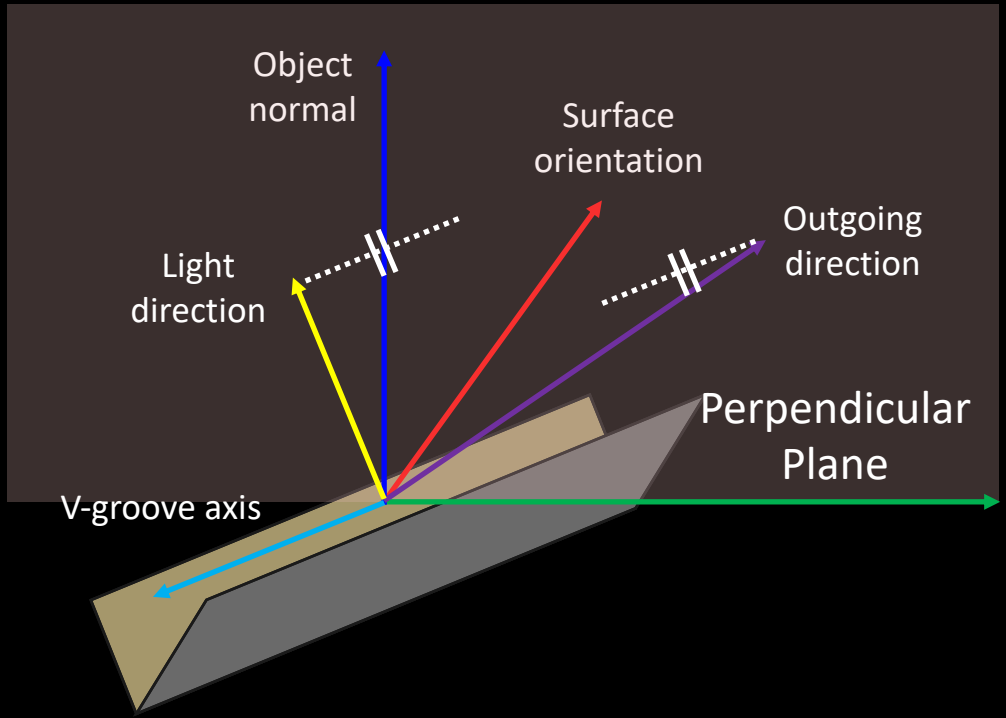


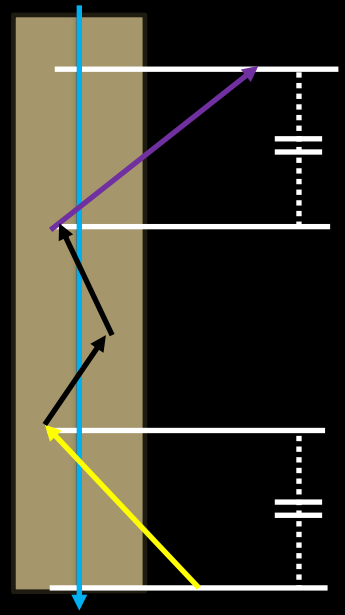


K-REFLECTION BRDF EVALUATION



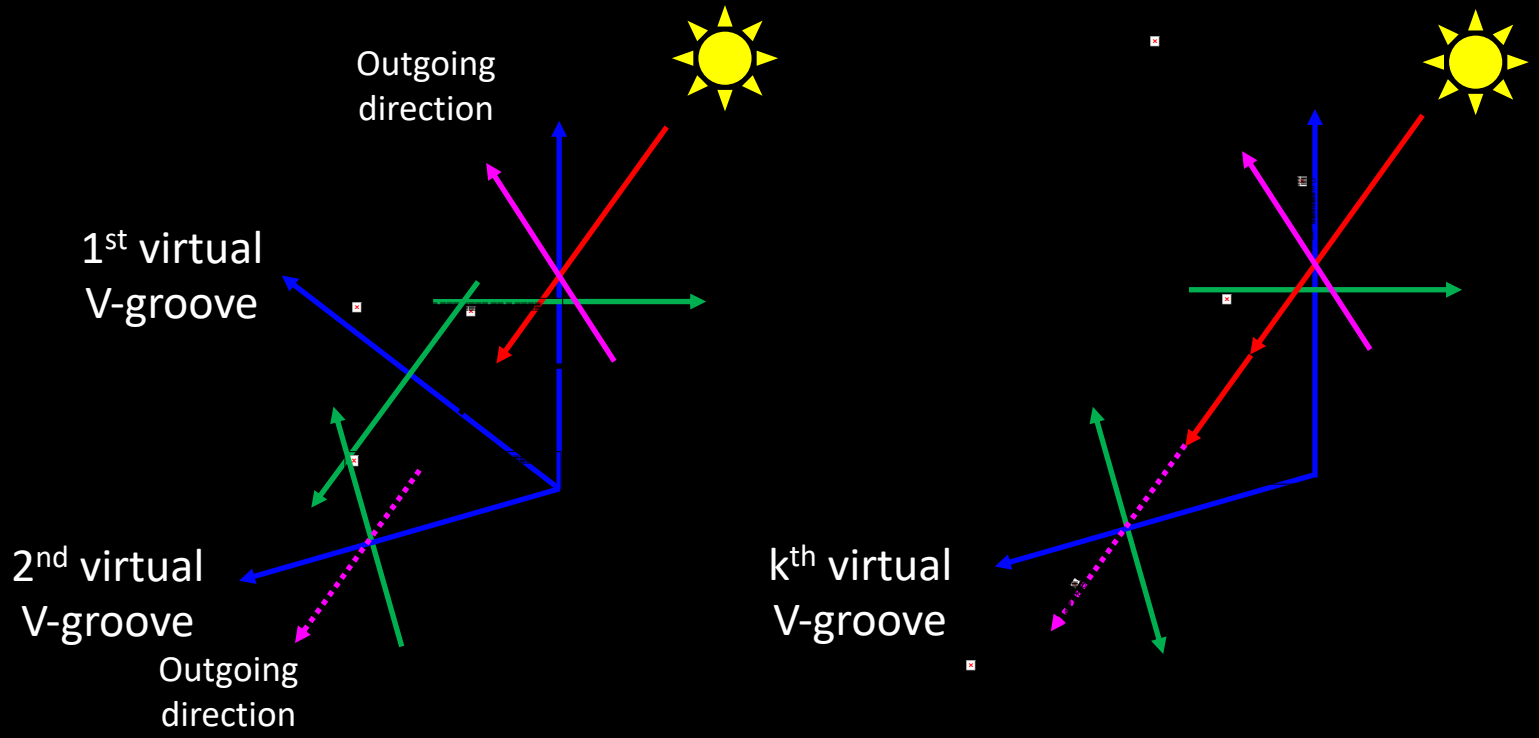
REFLECTION GEOMETRY





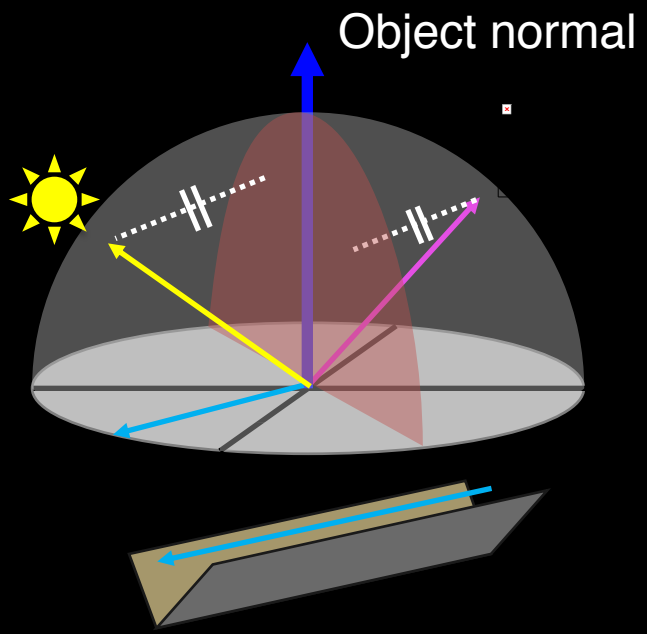
Top view

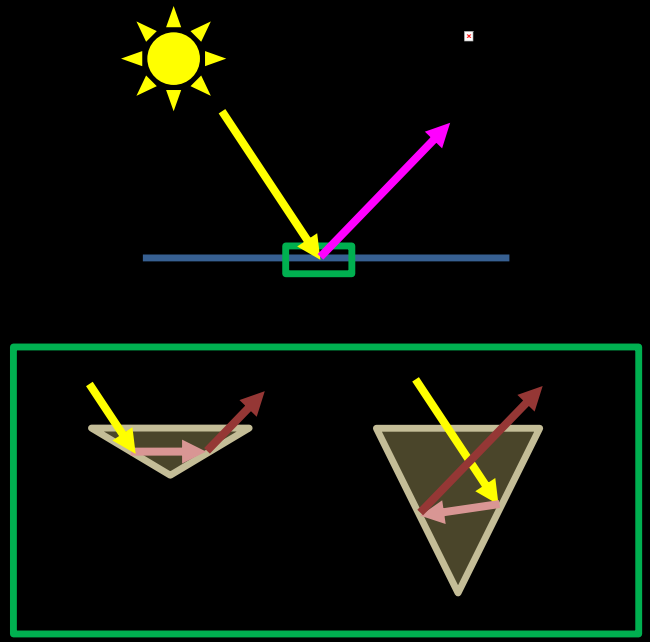
LIGHT TRANSPORT



[Zipin 1967]

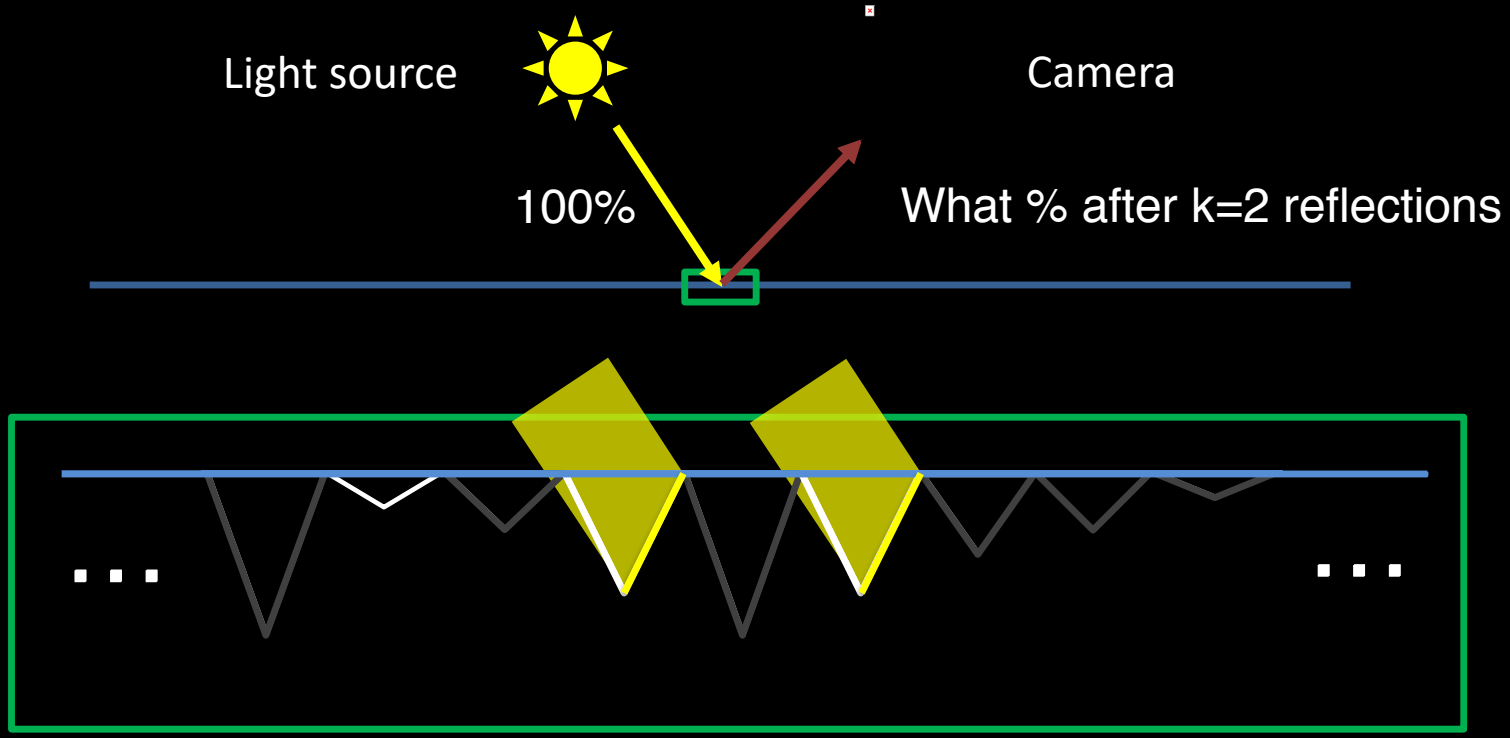
REFLECTION GEOMETRY



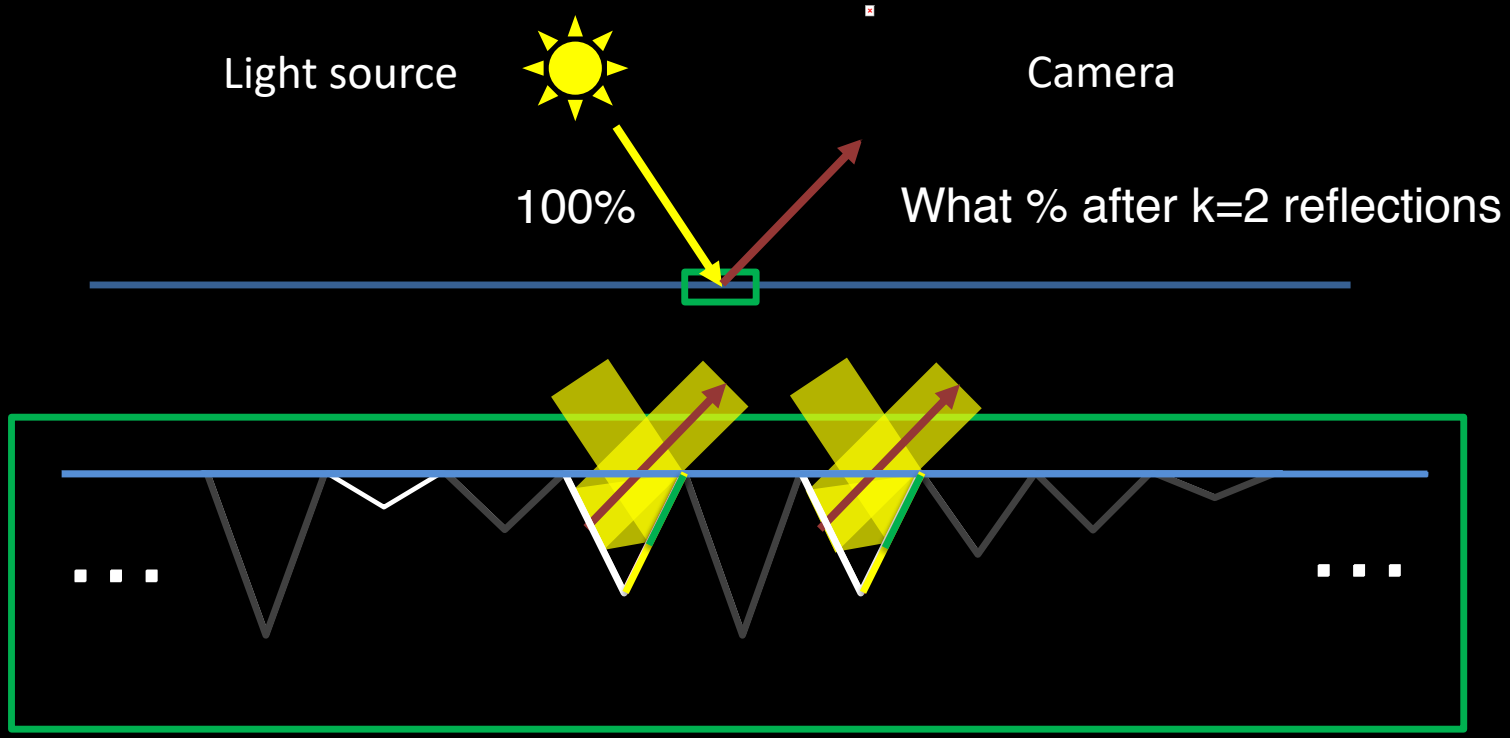


2 possible V-grooves

K-REFLECTION BRDF



K-REFLECTION BRDF



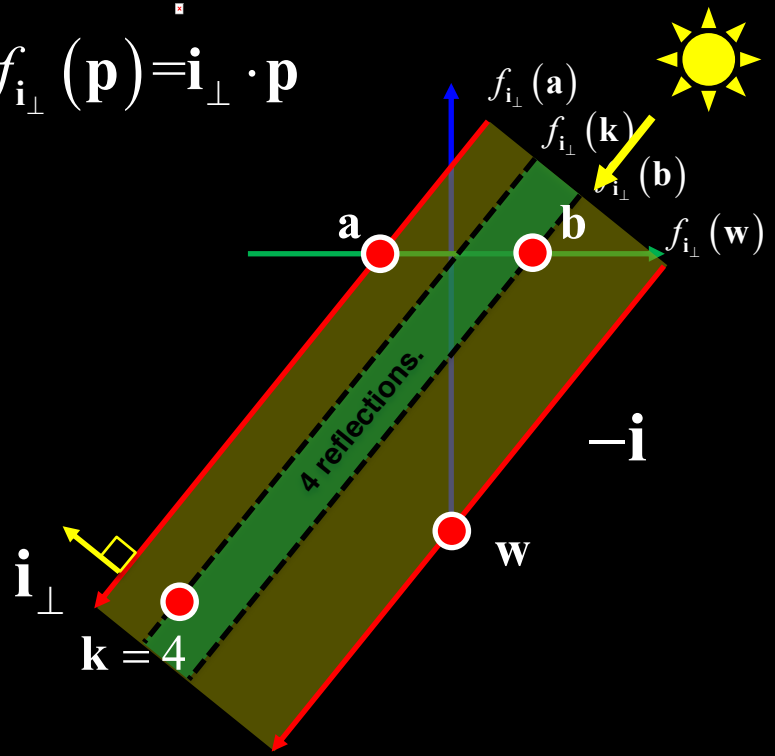
GEOMETRIC ATTENUATION

- Use line equation $f_{\mathbf{i}_\perp}(\mathbf{p}) = \mathbf{i}_\perp \cdot \mathbf{p}$

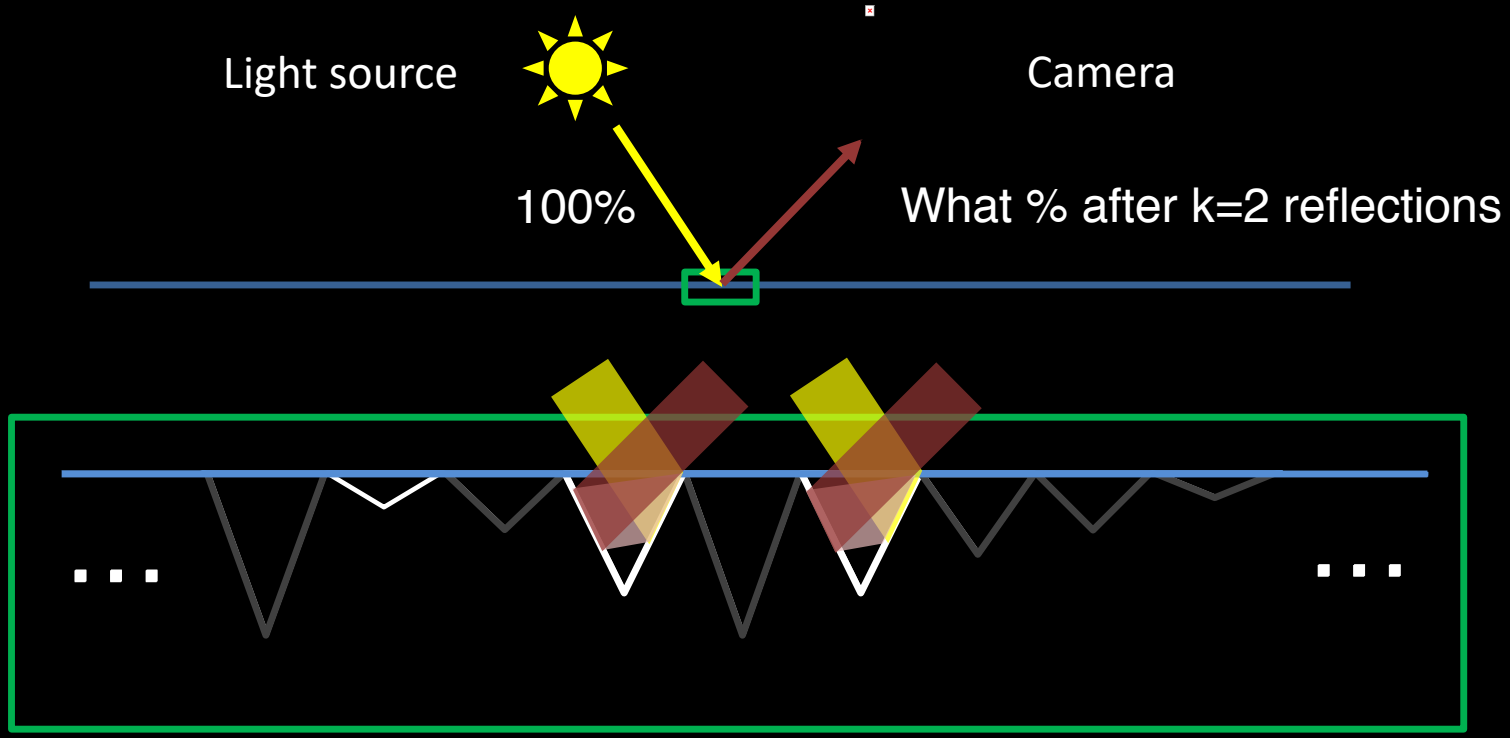
$$G(\mathbf{i},\mathbf{s},4) = \frac{f_{\mathbf{i}_\perp}(\mathbf{k}) - f_{\mathbf{i}_\perp}(\mathbf{b})}{f_{\mathbf{i}_\perp}(\mathbf{a}) - f_{\mathbf{i}_\perp}(\mathbf{w})}$$

K-reflection region

Total region



K-REFLECTION BRDF

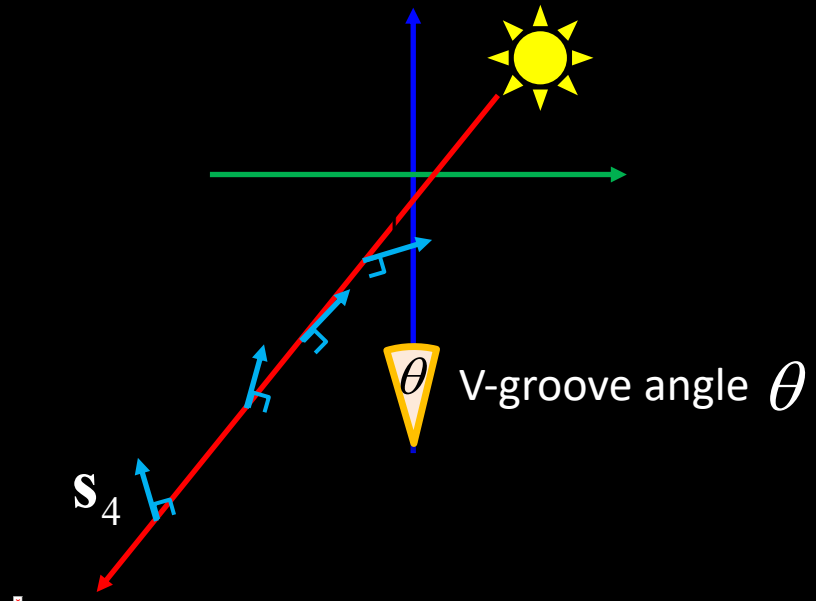


MULTIPLE FRESNEL EFFECT

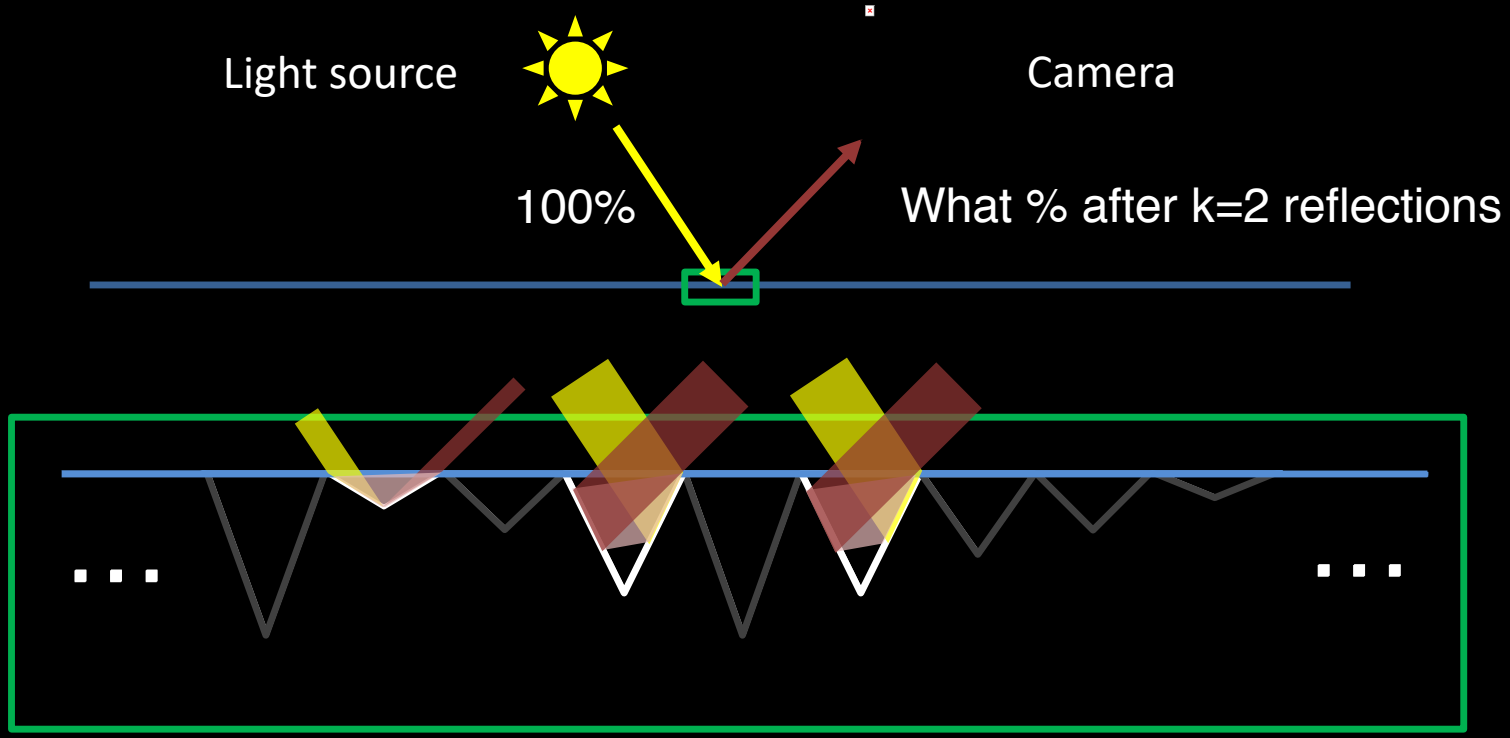
Total reflections $= \prod_{j=1}^{k} F\left(\mathbf{i} \cdot \mathbf{s}_j\right)$

Fresnel Effect at j-th bounce

$$\mathbf{s}_{i+1} = \begin{bmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{bmatrix} \mathbf{s}_i$$

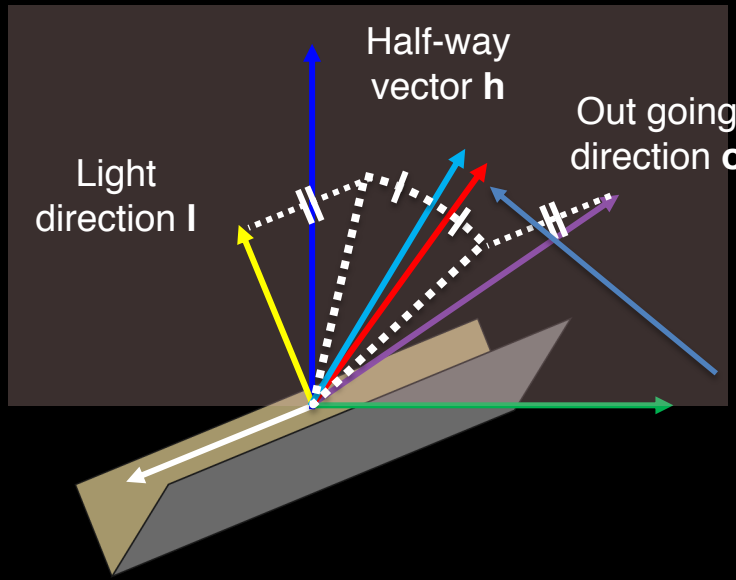


K-REFLECTION BRDF



PROJECTION FACTOR

- Distribution projection from the first-hit normal distribution to the outgoing distribution



$$\left|\frac{\mathbf{ds}}{\mathbf{do}}\right| = \left|\frac{\mathbf{ds}}{\mathbf{dh}}\frac{\mathbf{dh}}{\mathbf{do}}\right| = \frac{\sin\theta_s}{\sin\theta_h}\frac{1}{\pm k}\frac{1}{4\cos\theta_d}$$

K-REFLECTION BRDF MODEL

Projection factor

Fresnel effect

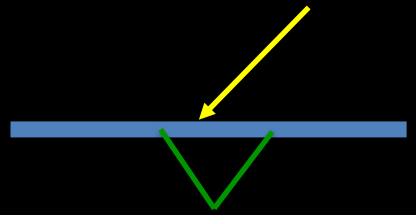
Geometric attenuation

Incident energy

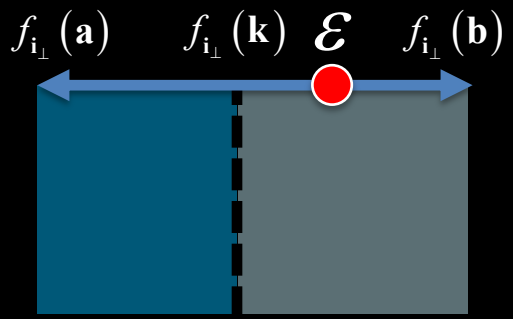
$$\rho(\mathbf{i},\mathbf{o},k)=\sum_{m=1}^{2}\frac{\sin\theta_{\mathbf{s}_m}}{k\sin\theta_{\mathbf{h}}\,4\cos\theta_{\mathbf{h}}}\frac{\prod_{j=1}^{k}F(\mathbf{i}\cdot\mathbf{s}_m^j)\,G(\mathbf{i},\mathbf{o},\mathbf{s}_m,k)}{(\mathbf{n}\cdot\mathbf{i})(\mathbf{n}\cdot\mathbf{o})}N(\mathbf{s}_m)|\mathbf{i}\cdot\mathbf{s}_m|$$

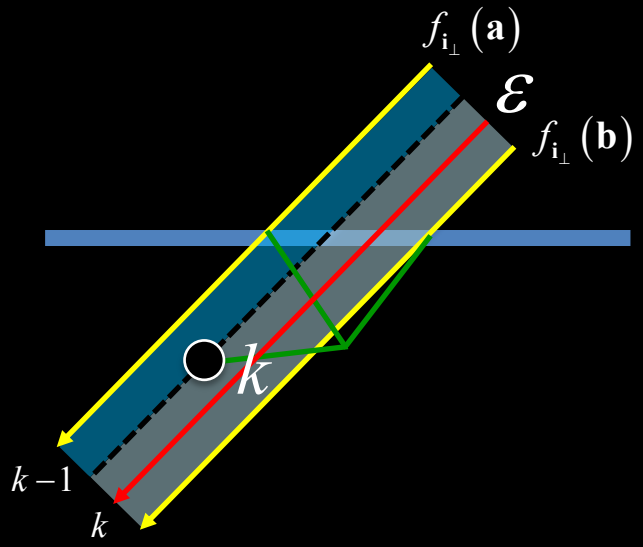
IMPORTANCE SAMPLING

1. Sample the first-hit surface



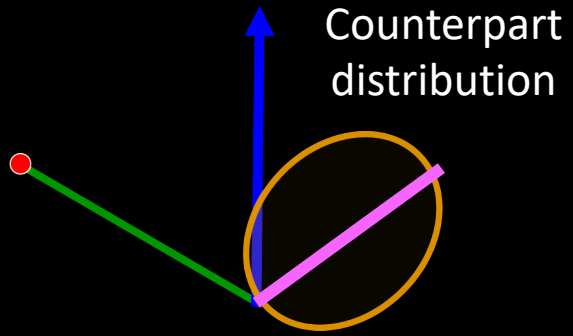
2. Sample the number of reflection k

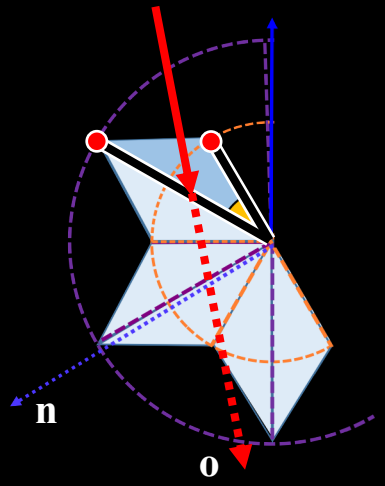


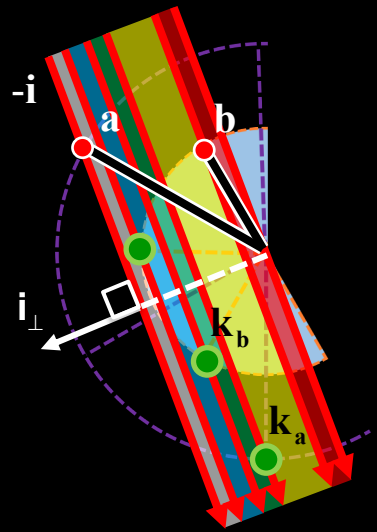


NONSYMMETRIC V-GROOVE

- Bivariate distribution
- Reflection geometry in virtual geometry

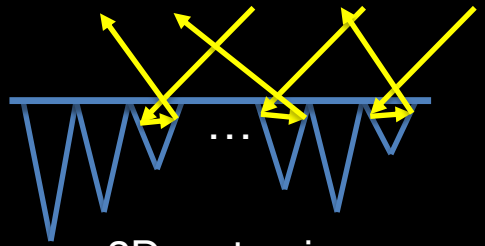






VALIDATION

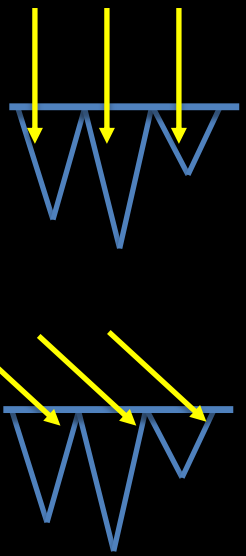
- Comparison against 2D ray simulation

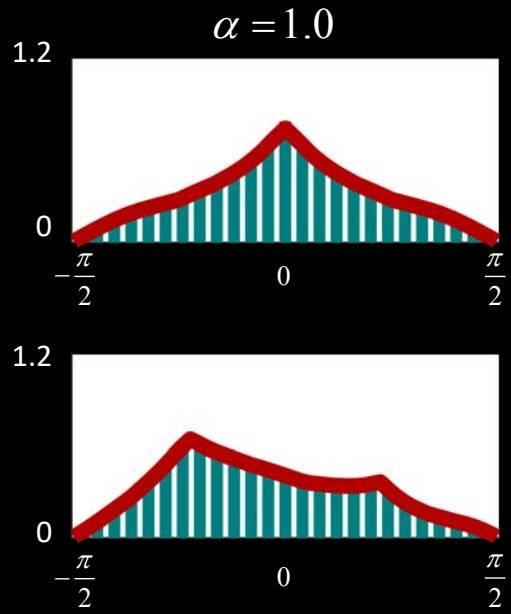


Symmetric $$\rho(\mathbf{i},\mathbf{o},k)=\sum_{m=1}^{2}\left|\frac{d\mathbf{s}_m}{d\mathbf{o}}\right|\frac{G(\mathbf{i},\mathbf{o},\mathbf{s}_m,k)}{(\mathbf{n}\cdot\mathbf{i})(\mathbf{n}\cdot\mathbf{o})}N(\mathbf{s}_m)|\mathbf{i}\cdot\mathbf{s}_m|$$

Non-symmetric $$\rho(\mathbf{i},\mathbf{o},k)=\int_{-\pi/2}^{\pi/2}\left|\frac{d\mathbf{s}_l}{d\mathbf{o}}\right|\frac{G(\mathbf{i},\mathbf{o},\mathbf{s}_l,\mathbf{s}_r,k)\rho(\mathbf{s}_r)}{(\mathbf{n}\cdot\mathbf{i})(\mathbf{n}\cdot\mathbf{o})}N(\mathbf{s}_l)|\mathbf{i}\cdot\mathbf{s}_l|d\theta_r$$

Our total BRDF $$\rho(\mathbf{i},\mathbf{o})=\sum_{k=1}^{N}\rho(\mathbf{i},\mathbf{o},k)$$



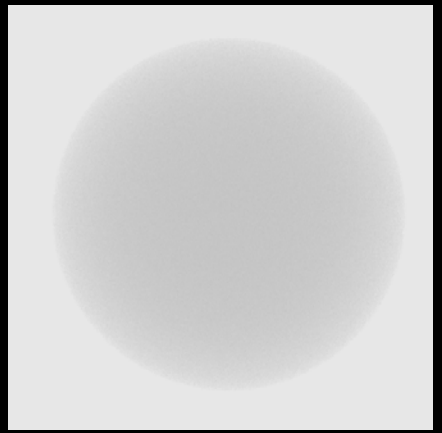


VALIDATION

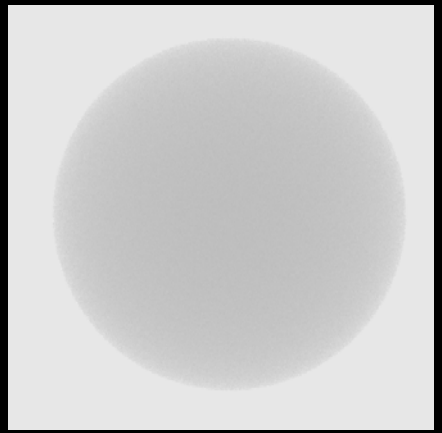
- Energy preservation

Single scattering

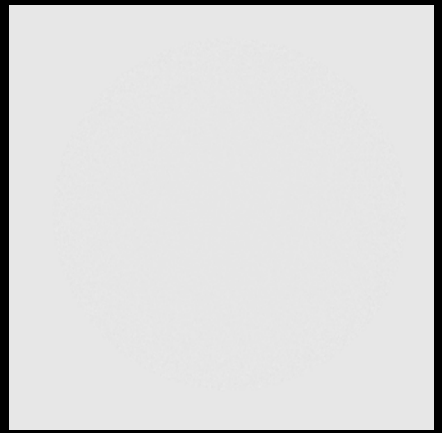
Multiple scattering



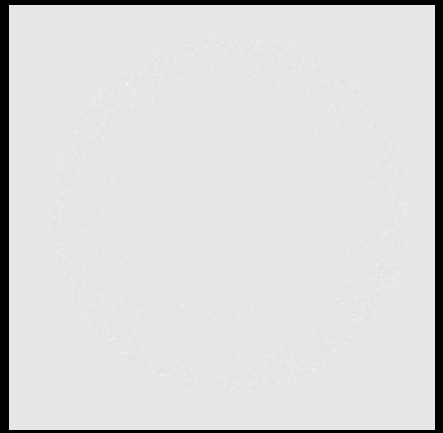
Symmetric



Nonsymmetric

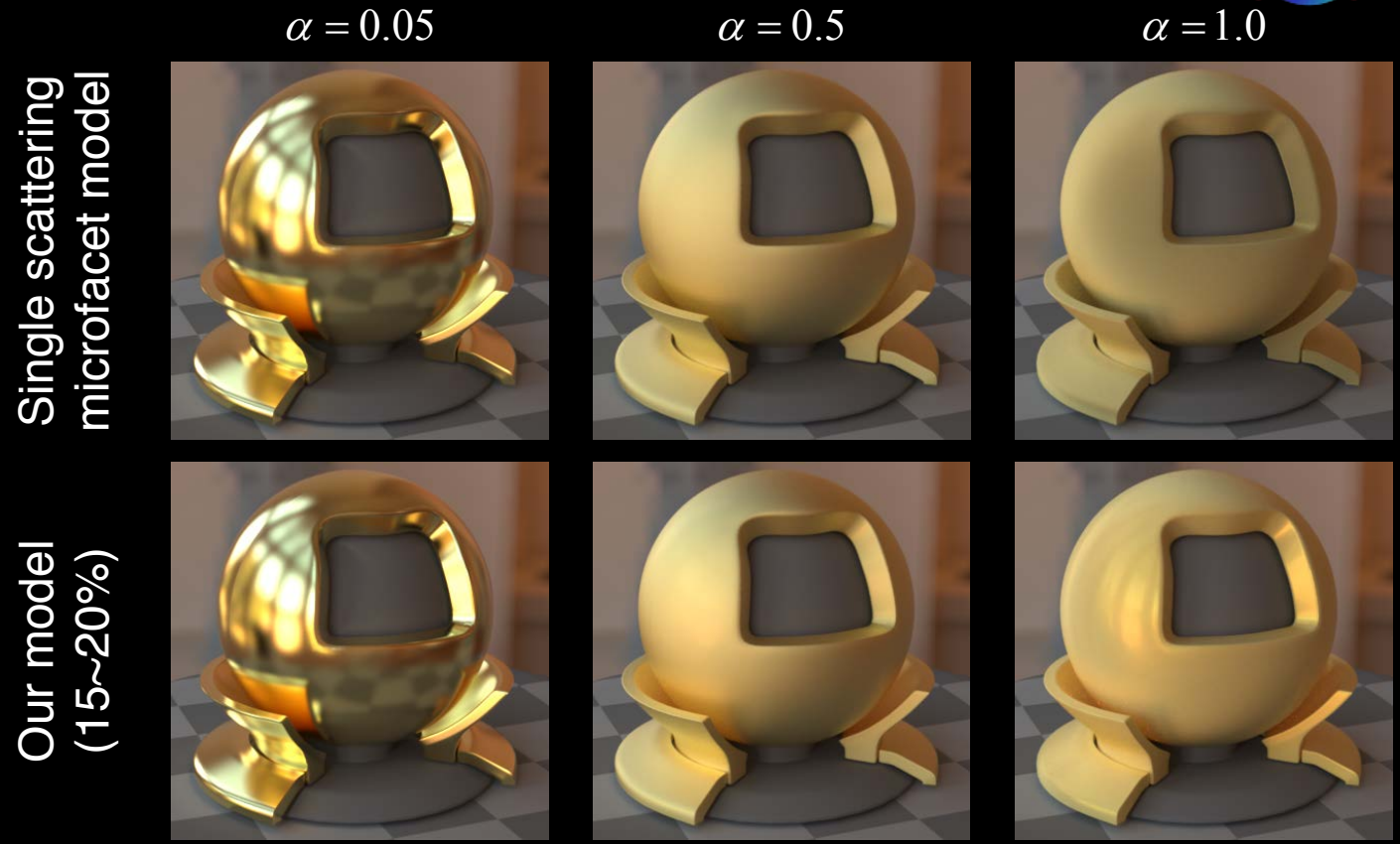


Symmetric

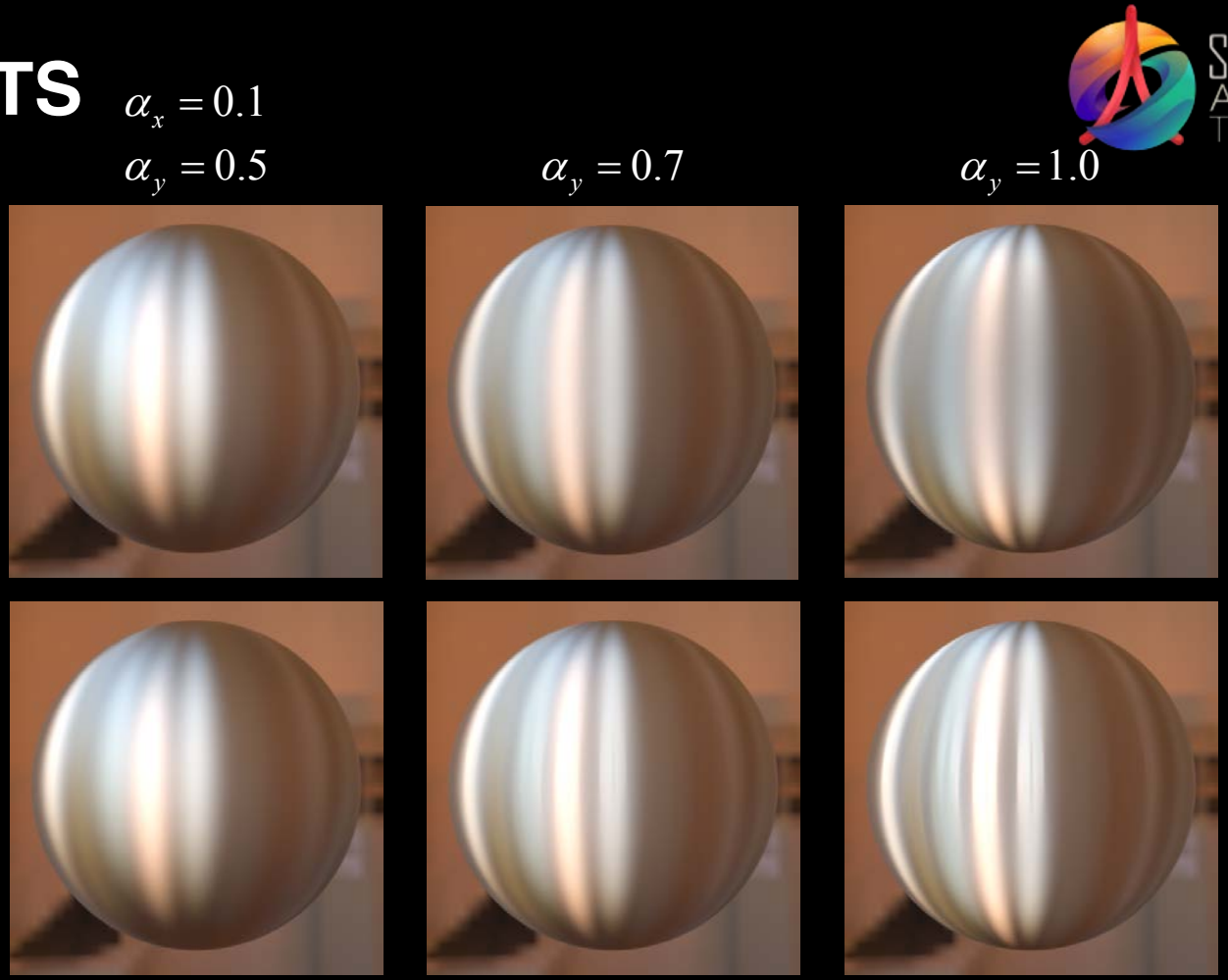


Nonsymmetric

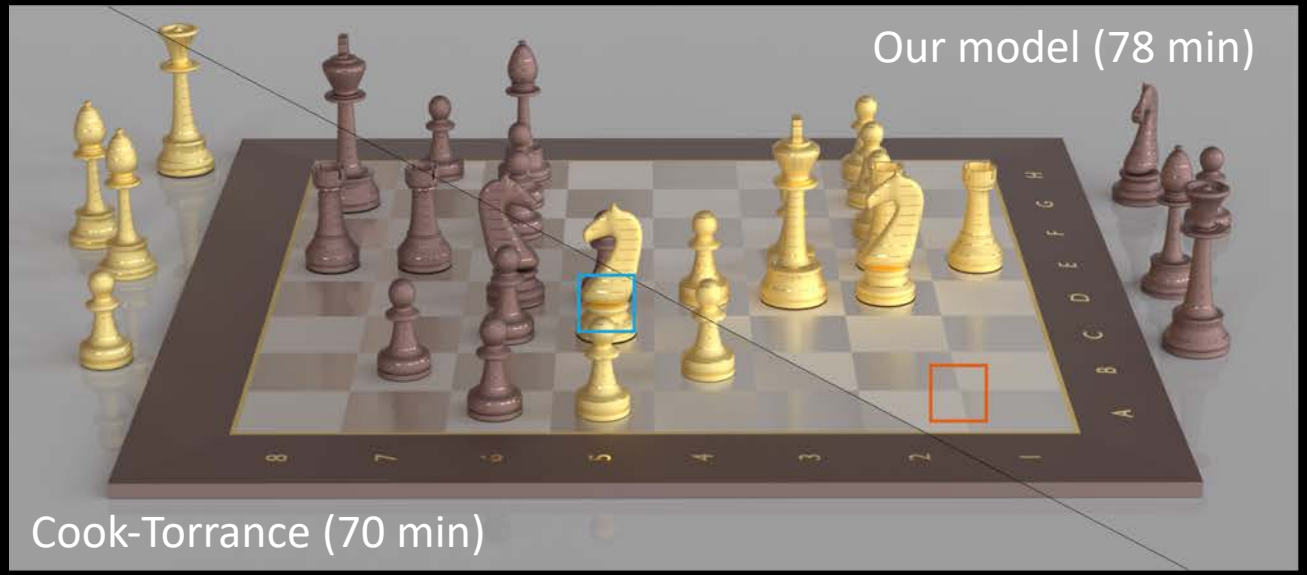
RESULTS Roughness



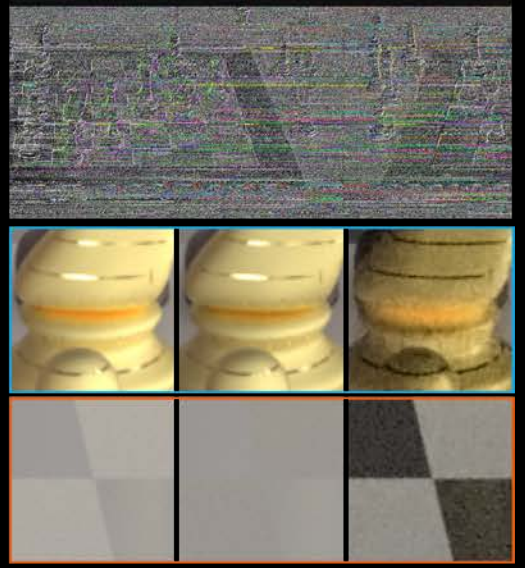
RESULTS


$\alpha_x = 0.1$
$\alpha_y = 0.5$
$\alpha_y = 0.7$
$\alpha_y = 1.0$
Single scattering microfacet model
Our model

RESULTS



1x difference



Ours | Cook-Torrance | 1x diff

CONCLUSION & FUTURE WORK

- An analytic model for multiple scattering
- Generalization of the Cook-Torrance model
- Non-parallel V-grooves

THANK YOU

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