

# MaterialX Retro Reflective BSDF Proposal

## Summary

This document proposes a new MaterialX retro reflective BRDF node based on the article “The Halfway Vector Disk for BRDF modeling” (*Edwards, et al 2006*) [1]. Retro-reflection is commonly found in materials used for safety: traffic signs, road markings, safety clothing and equipment, vehicle license plates, and bicycle reflectors. Automotive, Industrial and clothing companies developing digital twins for simulation and visualization have expressed a need for expanding the list of available BSDFs in MaterialX.

The proposed node is an empirical BSDF that uses a small number of parameters to represent the anisotropic roughness and tinting of the distribution function. Because we’re only focusing on a retro-reflective BSDF, we ignore the details in the paper as they pertain to specular reflection and only focus on equations in the retro-reflective direction.

The example implementation provided uses projected scaled halfway vectors (as opposed to orthogonal projection) to represent a PDF over a disk domain.

The BSDF is not symmetrical however and the implementation introduces two modifications which allow us to make a reciprocal BSDF with minimal energy loss. The BSDF works in both Real-Time application and fully path-traced simulations.

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## Parameters

The BSDF proposes a simple set of anisotropic roughness values, single scatter tint of the BSDF, and a reference tangent coordinate frame.

Parameters	Type	Range	Default	Description
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<b>roughness_u</b>	float	[0, ∞)	0	Roughness coefficient in the $u$ direction
<b>roughness_v</b>	float	[0, ∞)	roughness_u	Roughness coefficient in the $v$ direction
<b>tint</b>	color3	(0, 1)	1	Scaling factor, defined as a color, multiplied by the result of the distribution function.
<b>multiscatter_tint</b>	color3	(0, 1)	0	Scaling factor, defined as a color, of the diffuse multiscattering compensation; color(0.0) does not add any, color(1.0) fully compensates the energy loss.
<b>tangent_u</b>	float3		dP/du	tangent direction in $u$

## BSDF

The paper by Edwards et. al proposes a general framework for using halfway vector disk to represent the PDF over a disk domain. For simplicity, we remove equations as they pertain to forward specular BRDFs and provide only the necessary formulas.

Edwards has several key formulas used to create the BSDF. The first scales the halfway vectors into 2-dimension points that lie on the base of a hemisphere.

$$h = \frac{(\omega_o \cdot N)}{(H \cdot N)} H, \text{ (Eq. 15)}$$

The second formula describes a PDF of halfway vectors on a disk using a gaussian “lump” function. The exponent  $n$  controls the tightness or width of the lump and includes an anisotropic form that uses an elliptical function with different radii.

$$p(h) = \frac{n+1}{\pi R^2} \left[ 1 - \frac{\|h - c\|^2}{R^2} \right]^n, \text{ (Eq. 26)}$$

The lump functions centered in the retro-reflective direction produces the PDF:

$$p(h) = \frac{n_r+1}{\pi R_r^2} \left[ 1 - \frac{\|h - \omega_{ou v}\|^2}{R_r^2} \right]^{n_r}, \text{ (Eq. 32 simplified where } k = 1)$$

The final derived BRDF is therefore:

$$\rho(\omega_i, \omega_o) = \frac{p(h)(\omega_o \cdot N)^2}{4(\omega_i \cdot N)(\omega_i \cdot H)(H \cdot N)^3}, \text{ (Eq. 20 \& 33)}$$

## Practical Implementation

[MDL Github](#) (“NVIDIA Material Definition Language SDK”, n.d.)

### Roughness

Internally the disk distribution method makes use of an exponent to control the size of the reflectance. To maintain the use of roughness we use the following conversion where  $uv$  is the anisotropic roughness values. The conversion is non-linear however and ideally we would like a more roughness that provides more fine control

$$n_{uv} = \frac{2}{roughness_{uv}^2}$$

### BRDF Reciprocity

Closer inspection of the paper shows that this BRDF is asymmetric and not physically plausible. The MDL implementation therefore draws from the Ashikhmin et. al 2000 and Neumann et. al 1999 papers and implements two modifications to enforce reciprocity.

Firstly, instead of using a disk distribution  $p(h, \omega_o)$  centered around the outgoing direction  $\omega_o$ , the minimum value of two distributions, one centered around the outgoing direction  $\omega_o$  and one around the incoming direction  $\omega_i$  is used.

$$\min\{p(h, \omega_o), p(h, \omega_i)\}$$

Secondly in Neumann et. al 1999, the division by the cosine of the angle between the incoming direction and the normal,  $(\omega_i \cdot N)$  is replaced by a division by the maximum of the cosines of both the incoming and outgoing directions [3].

$$\frac{1}{\cos\theta_{min}} = \frac{1}{\max(\cos\theta_L, \cos\theta_V)}$$

where  $\theta_{min} = \min(\theta_L, \theta_V)$ . Using common notation the denominator becomes:

$$\frac{1}{\max\{(\omega_i \cdot N), (\omega_o \cdot N)\}}$$

The changes do introduce energy loss however. In practice, the loss seems negligible and for bi-directional path-tracers, we prefer reciprocity to energy loss. Additionally, these correction factors involve computing the PDF twice, which is not ideal.

The other consideration is that the framework uses an empirical lump function and is not physically based. In theory, any function could be used but we have not found any alternate proposals.

## Examples

Roughness 0.05

<https://youtube.com/shorts/Q80nYgUDbpE?feature=share>

Roughness 0.15

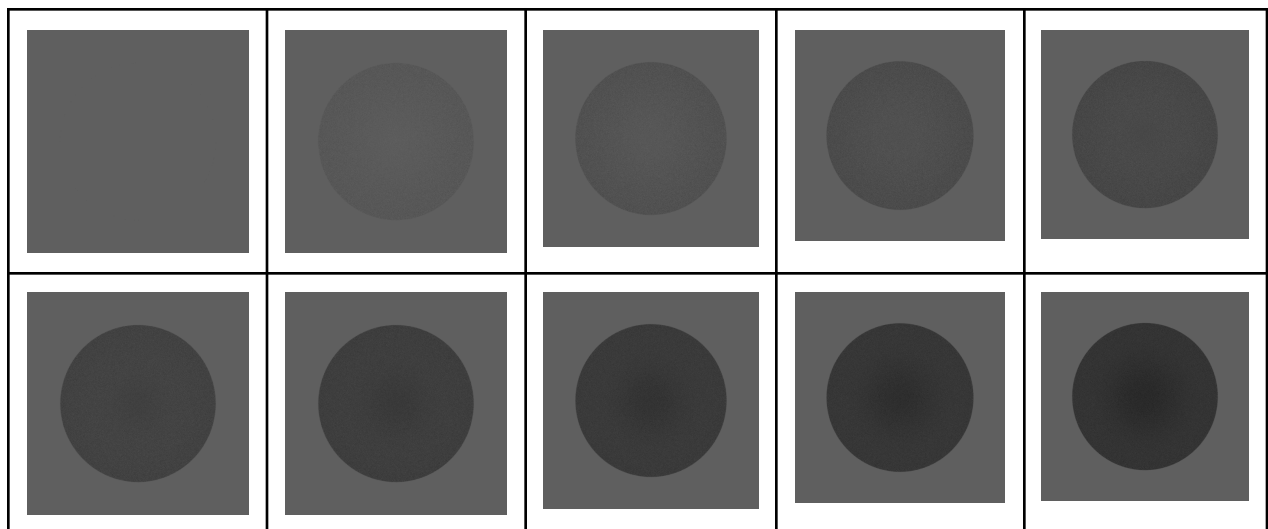
[https://youtube.com/shorts/8l\\_ecGd--1s](https://youtube.com/shorts/8l_ecGd--1s)

Roughness 0.5

<https://youtube.com/shorts/3O6hKeGwkiQ?feature=share>

## Furnace Tests

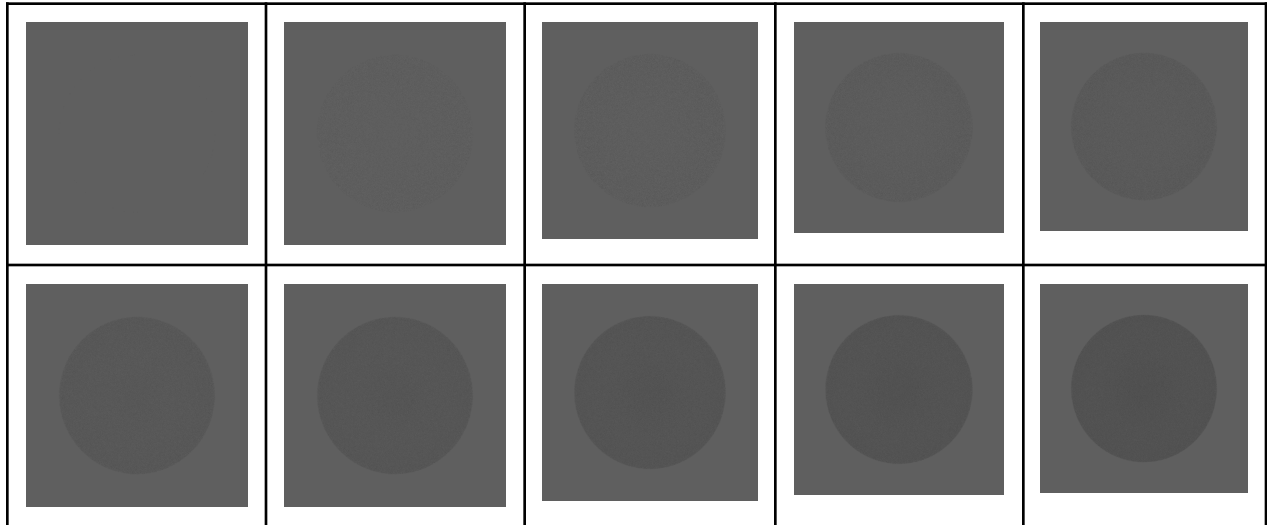
### Single Scattering



*Top Row: roughness 0, .1, .2, .3, .4, .5*

*Bottom Row: roughness .6, .7, .8, .9*

## Multiple Scattering



Top Row: roughness 0, .1, .2, .3, .4, .5

Bottom Row: roughness .6, .7, .8, .9

*Note: There is a new MDL bug fix with multi-scattering importance sample that results in no energy loss in test cases where multi-scatter tint = 1.0.*

## References

- [1] Edwards, Dave, et al. "The halfway vector disk for BRDF modeling." *ACM Transactions on Graphics (TOG)*, vol. 25, no. 1, 2006, pp. 1-18,  
<https://graphics.stanford.edu/~boulos/papers/brdftog.pdf>.
- [2] Ashikmin, Michael, et al. "A Microfacet-based BRDF Generator." *Siggraph Proceedings of the 27th annual conference on Computer Graphics and interactive techniques*, 2000, pp. 65-74, <https://graphics.stanford.edu/~boulos/papers/brdftog.pdf>.
- [3] Neumann, László, et al. "Compact Metallic Reflectance Models." *Computer Graphics Forum*, vol. 18, no. 3, 1999, pp. 161-172,  
[https://www.researchgate.net/publication/227631231\\_Compact\\_Metallic\\_Reflectance\\_Models](https://www.researchgate.net/publication/227631231_Compact_Metallic_Reflectance_Models).