

SSLPV: SUBSURFACE LIGHT PROPAGATION VOLUMES

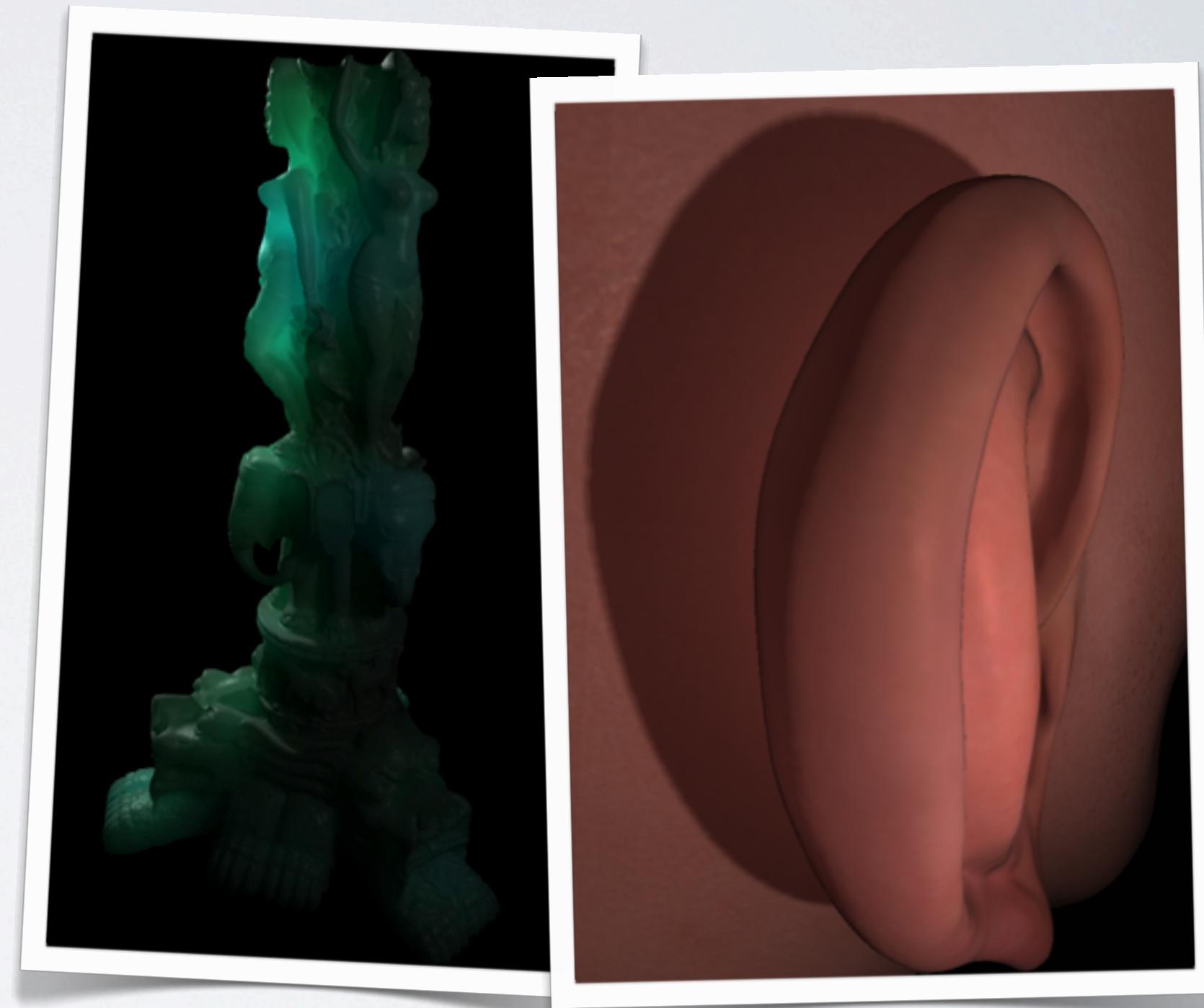
Jesper Børslum Brian Bunch Christensen Thomas Kim Kjeldsen
Peter Trier Mikkelsen Karsten Østergaard Noe Jens Rimestad
Jesper Mosegaard

Alexandra Institute, Denmark

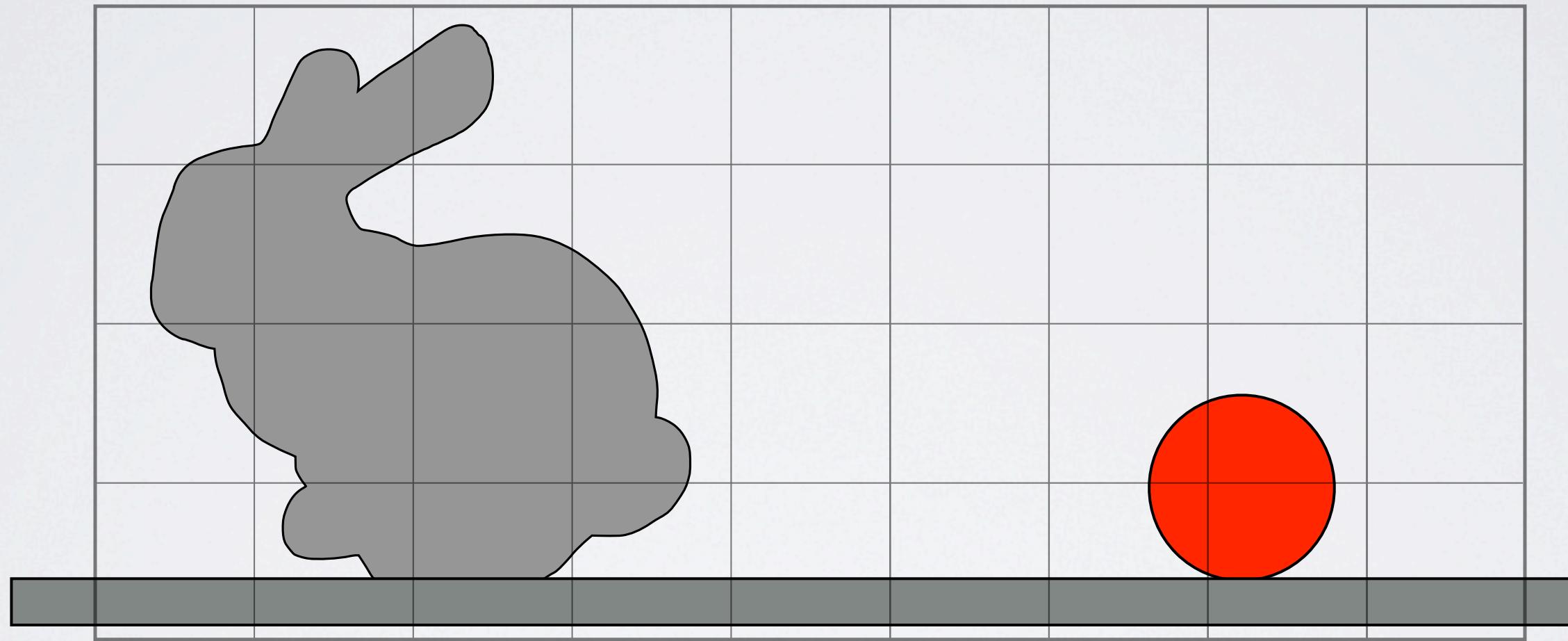


MOTIVATION

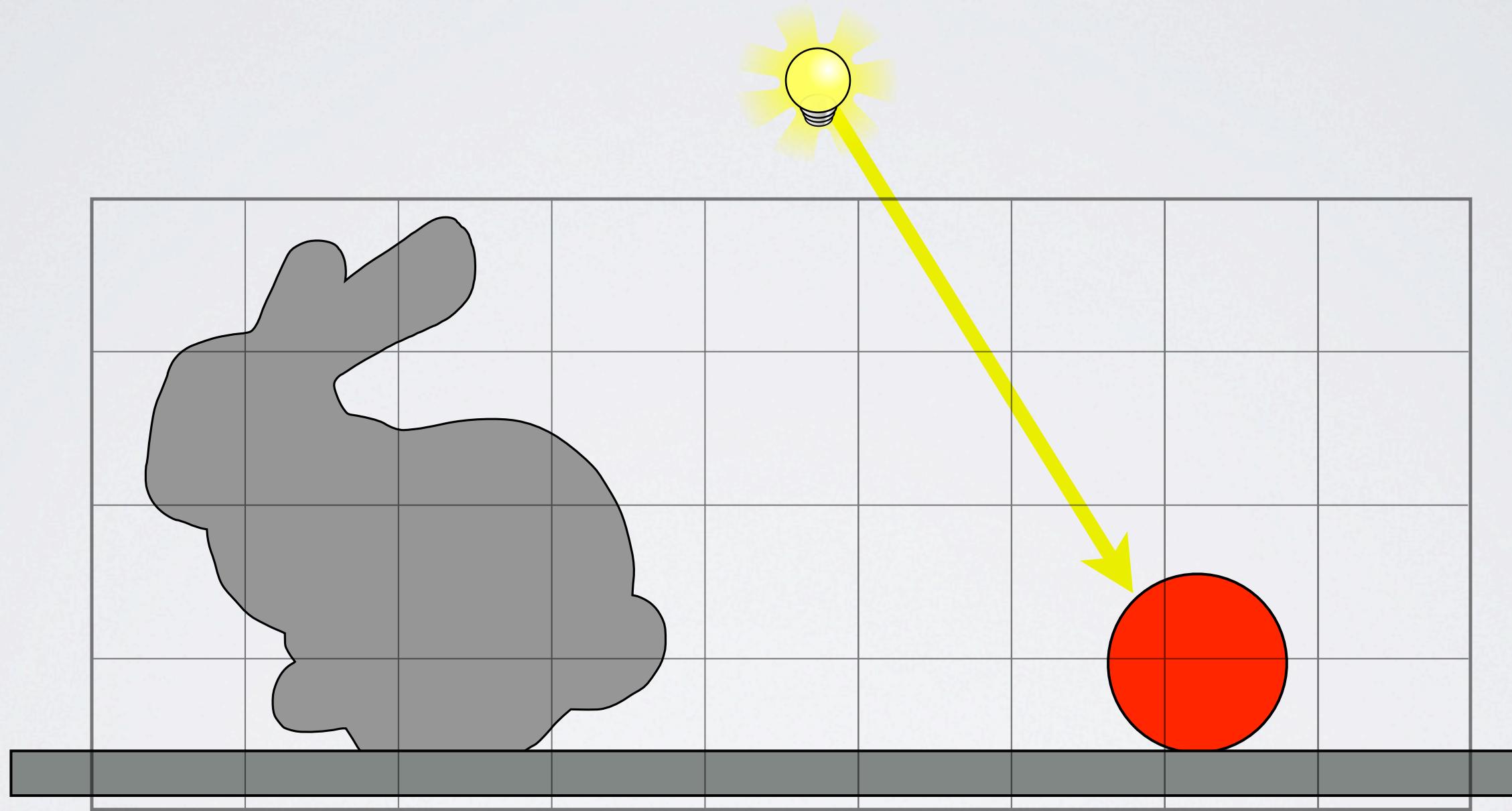
- Visually important
- Hard problem
- Performance and plausibility > Physical accuracy
- Dynamic environments



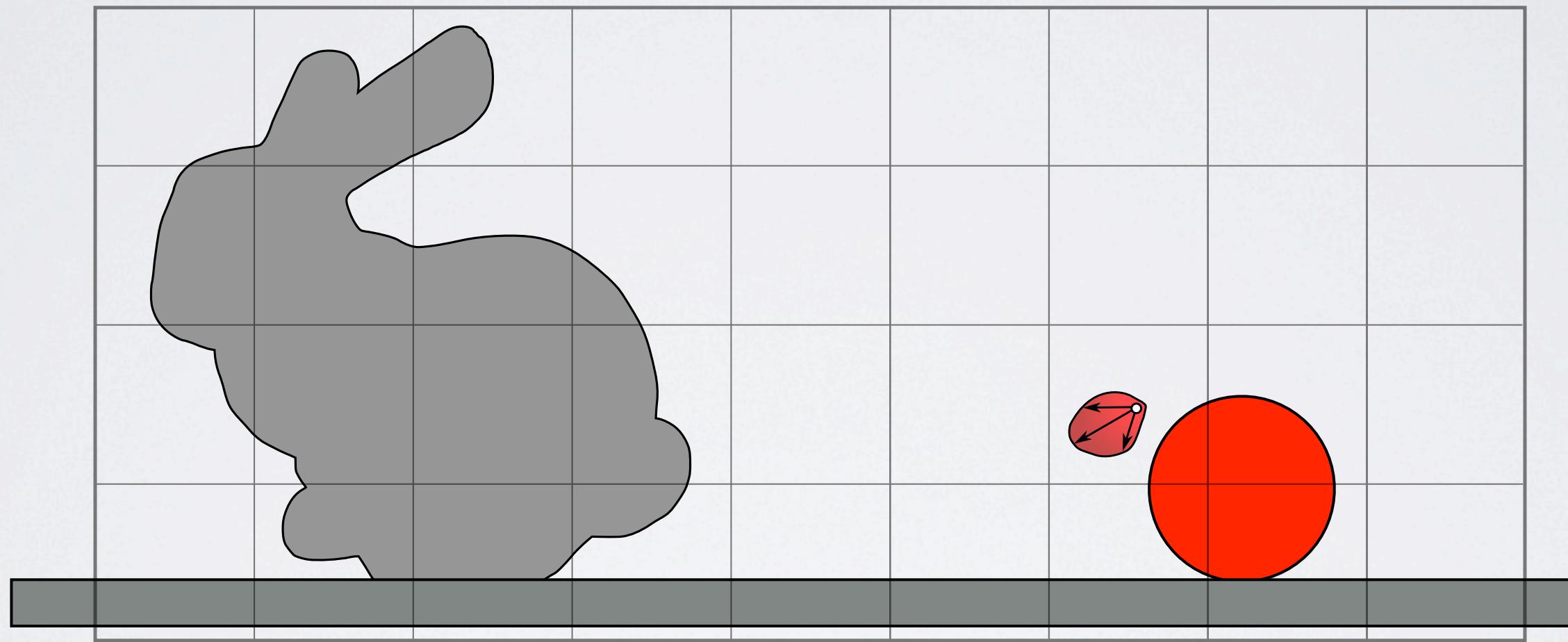
INTUITION



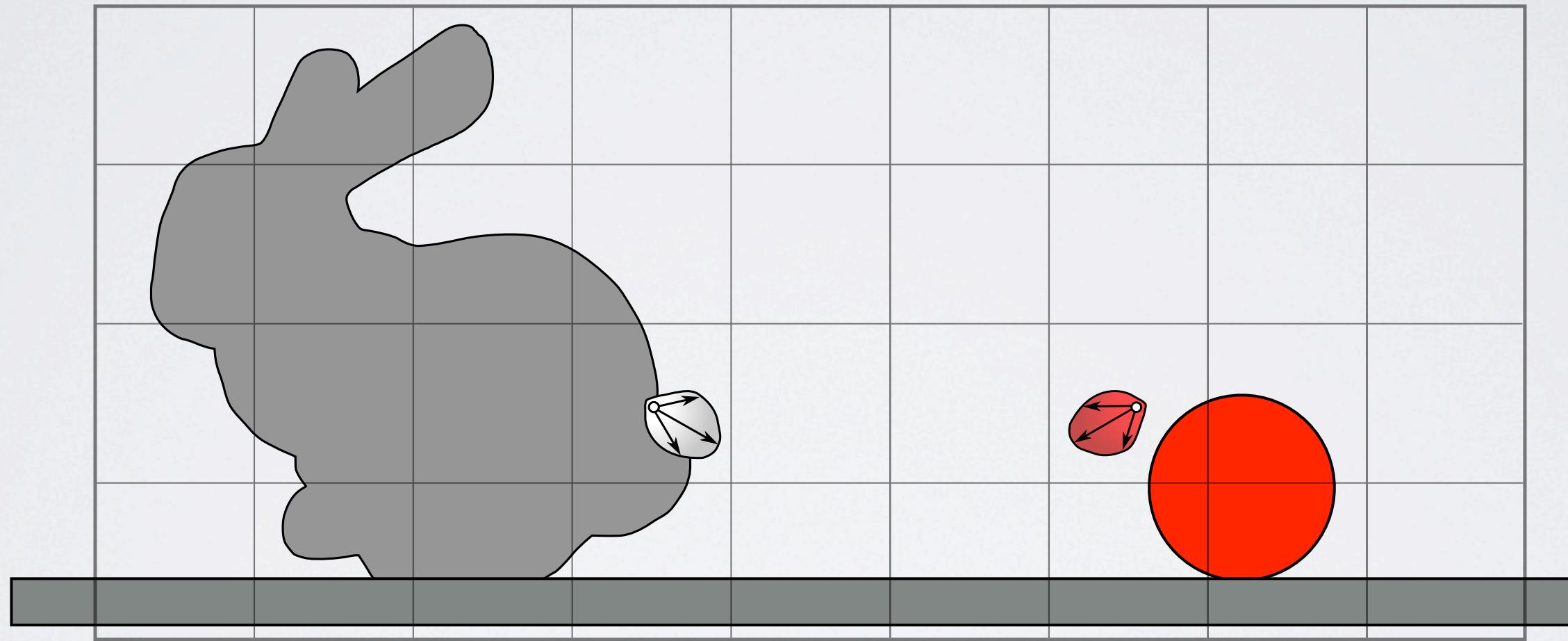
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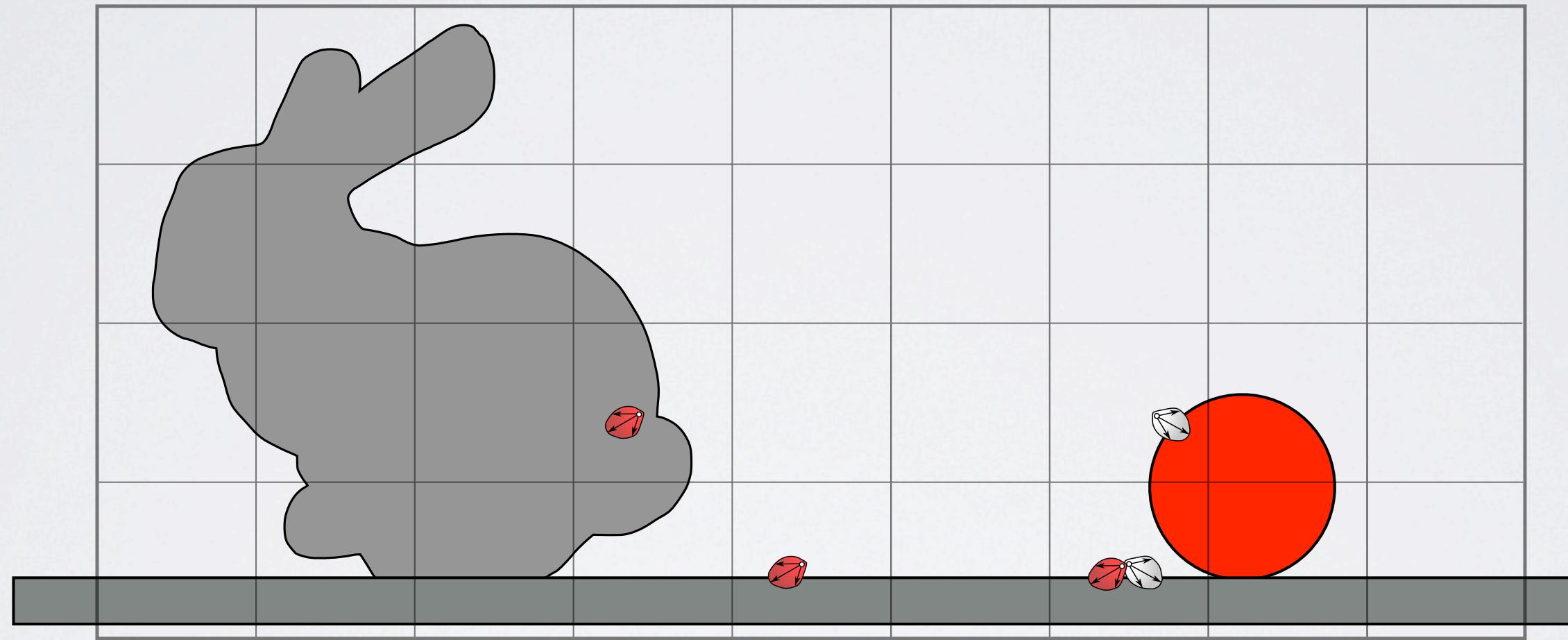
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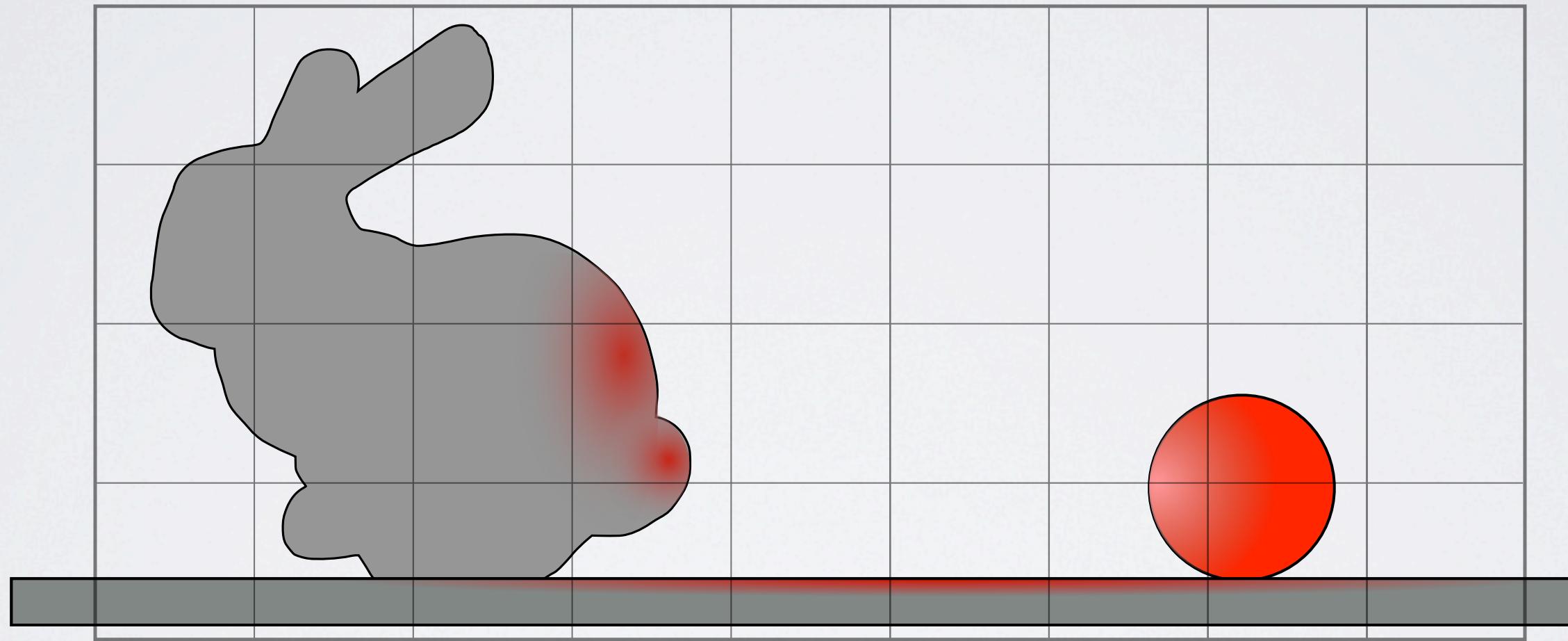
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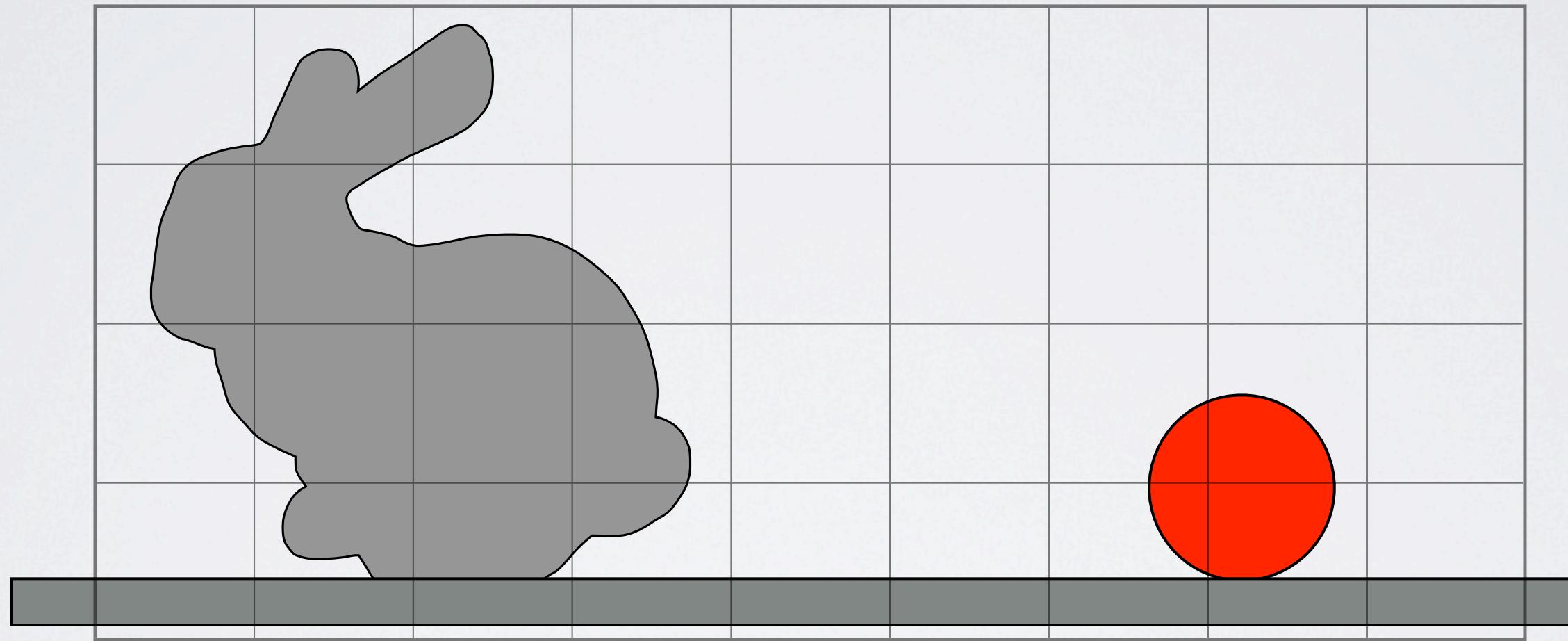
INTUITION



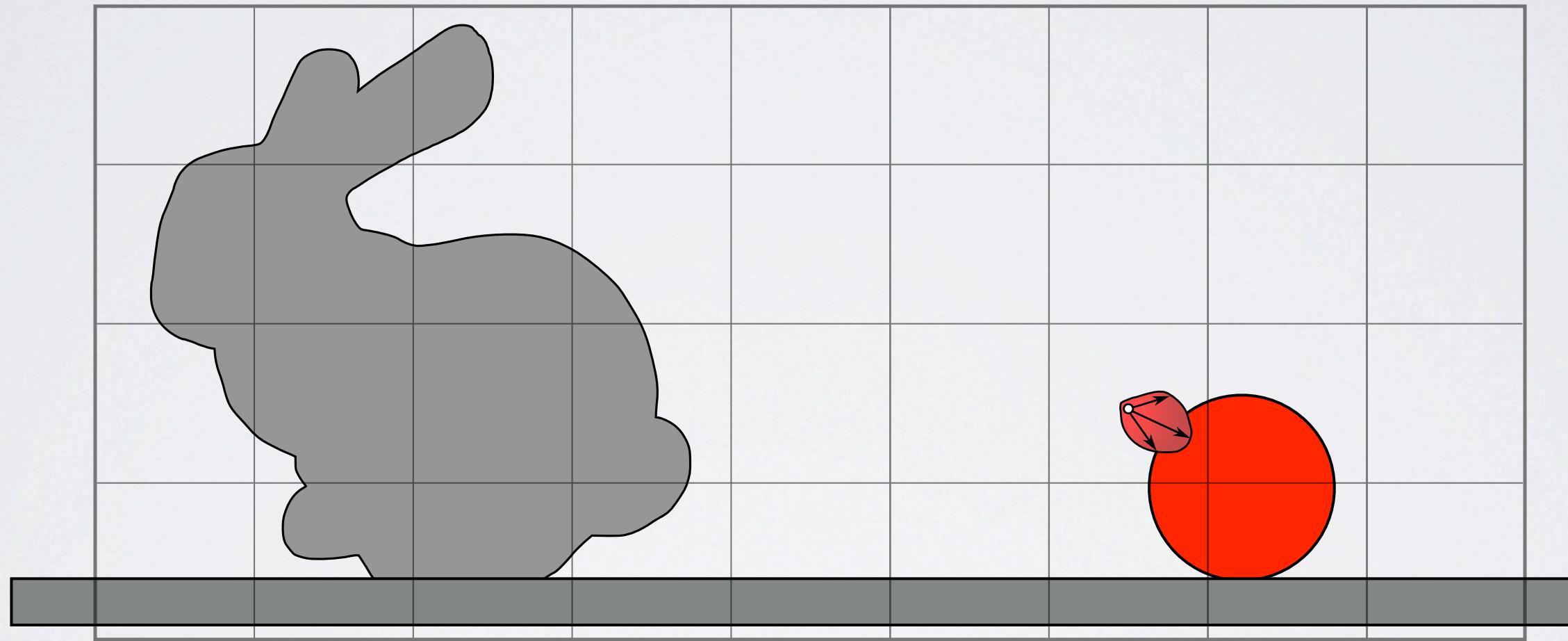
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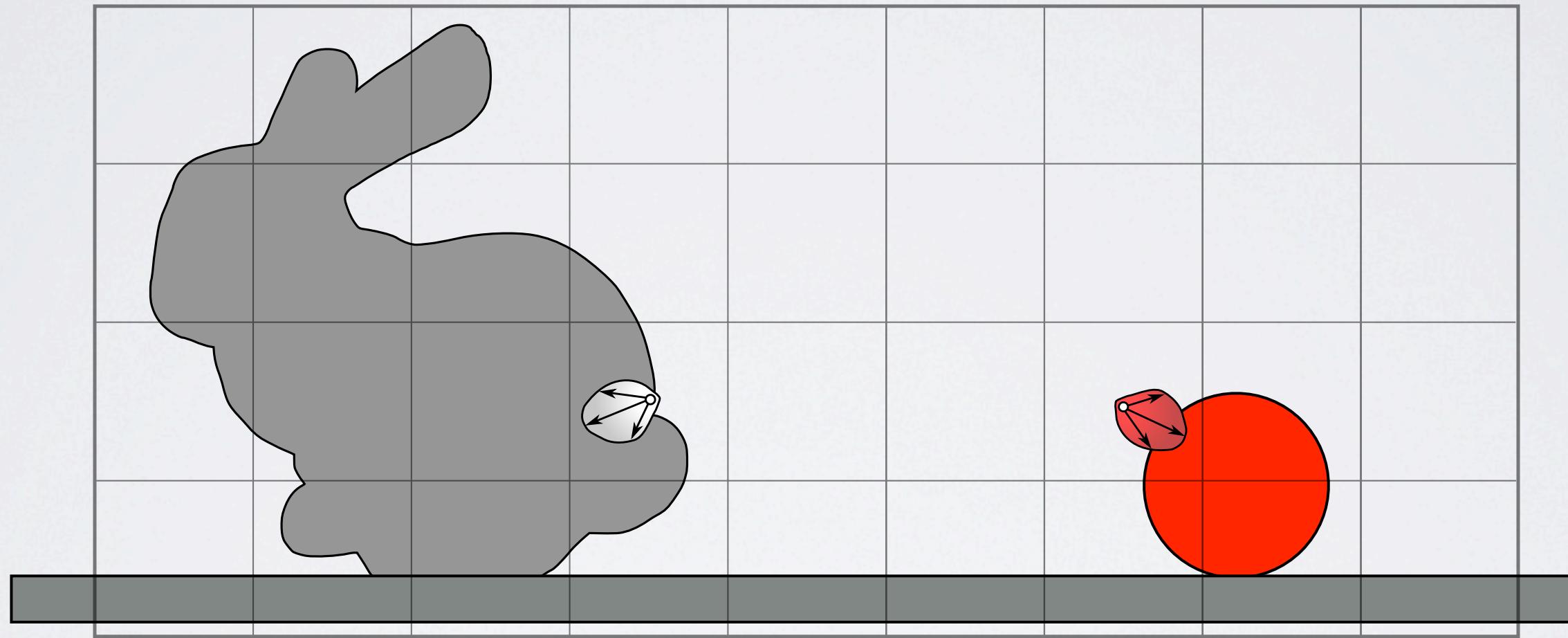
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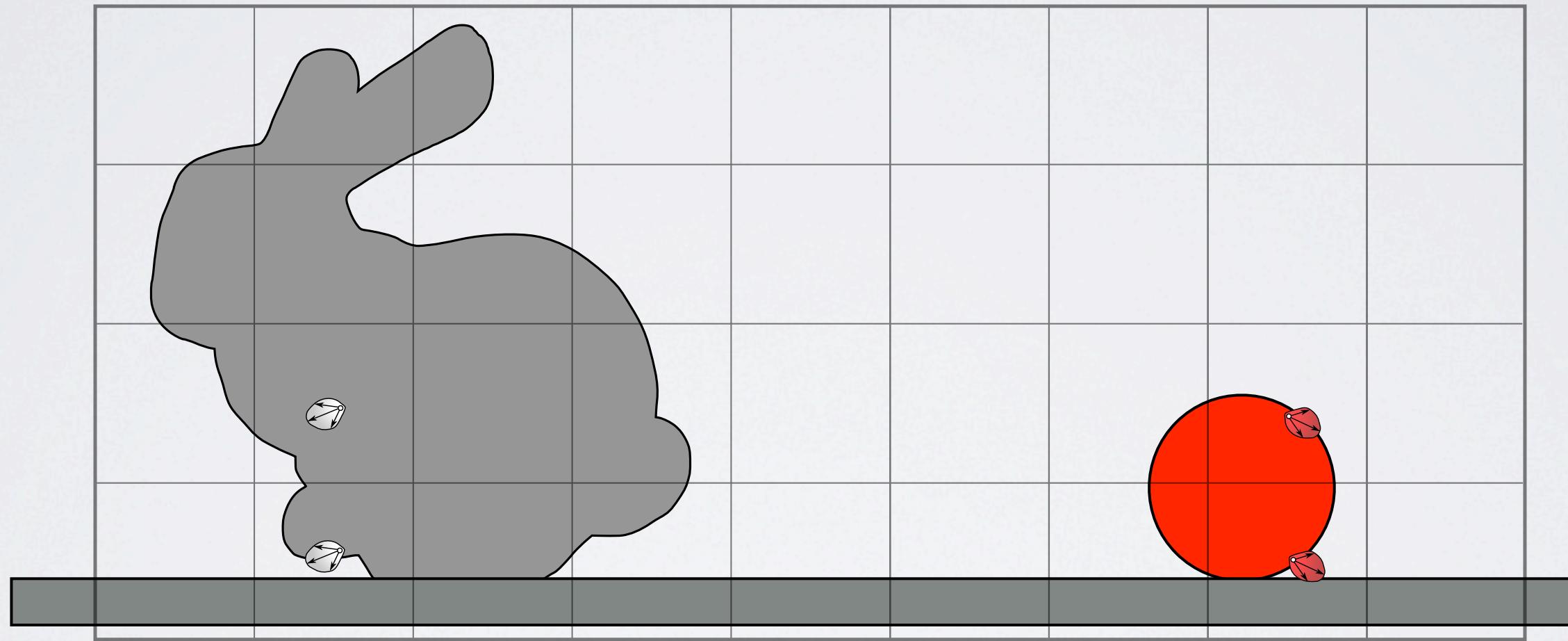
INTUITION



INTUITION



INTUITION



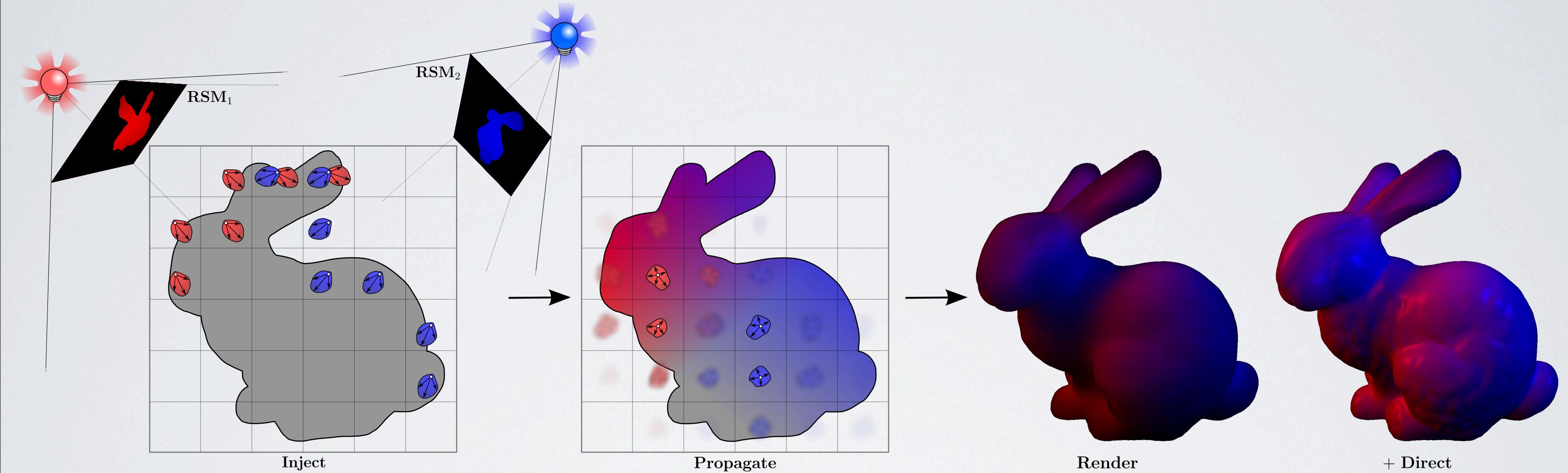
PREVIOUS WORK

- Light Propagation Volumes [Kaplanyan & Dachsbacher 2010]
- Dipole approximation [Jensen et al. 2001]
- Translucent Shadow Maps [Dachsbacher & Stamminger 2003]
- Diffusion equation on tetrahedral mesh [Wang et al. 2010]
- Lattice-Boltzmann Lighting [Geist & Westall 2011]

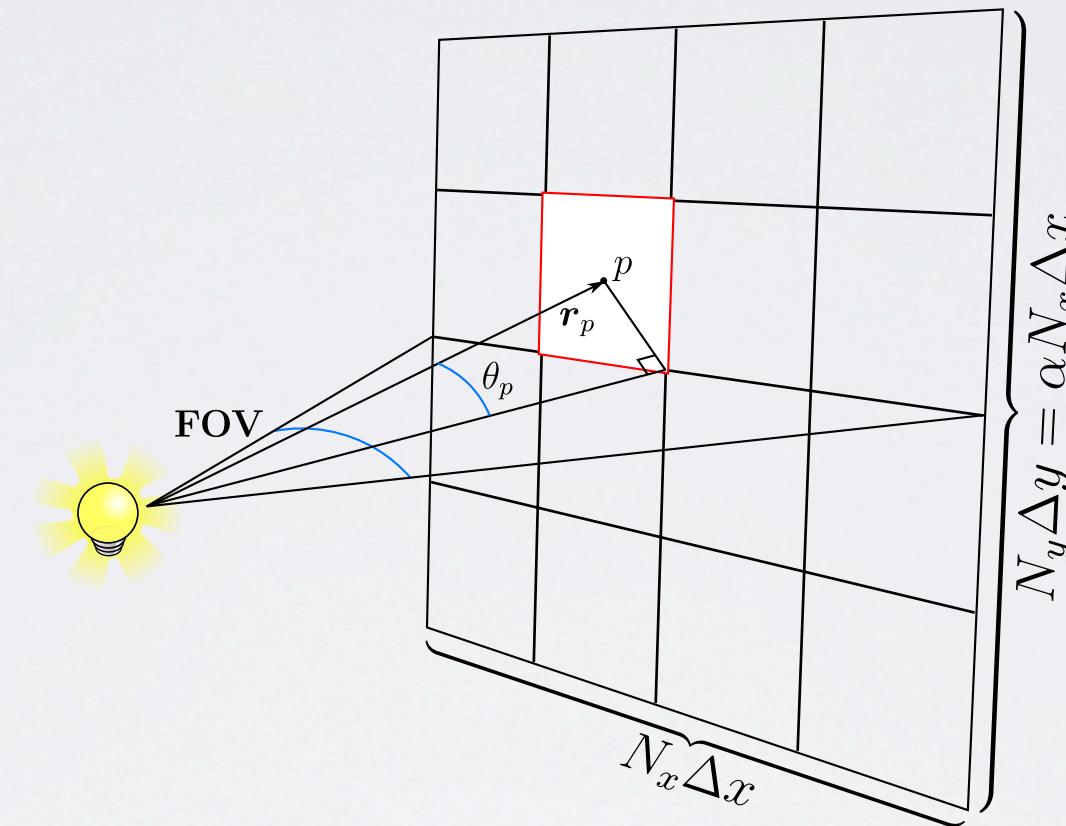
FEATURES

- A novel LPV based method for real-time subsurface scattering
- Support for arbitrarily deforming meshes
- A model for scattering and absorption effects
- A novel method for rendering using LPV grids
- Fits into an existing LPV pipeline

ALGORITHM



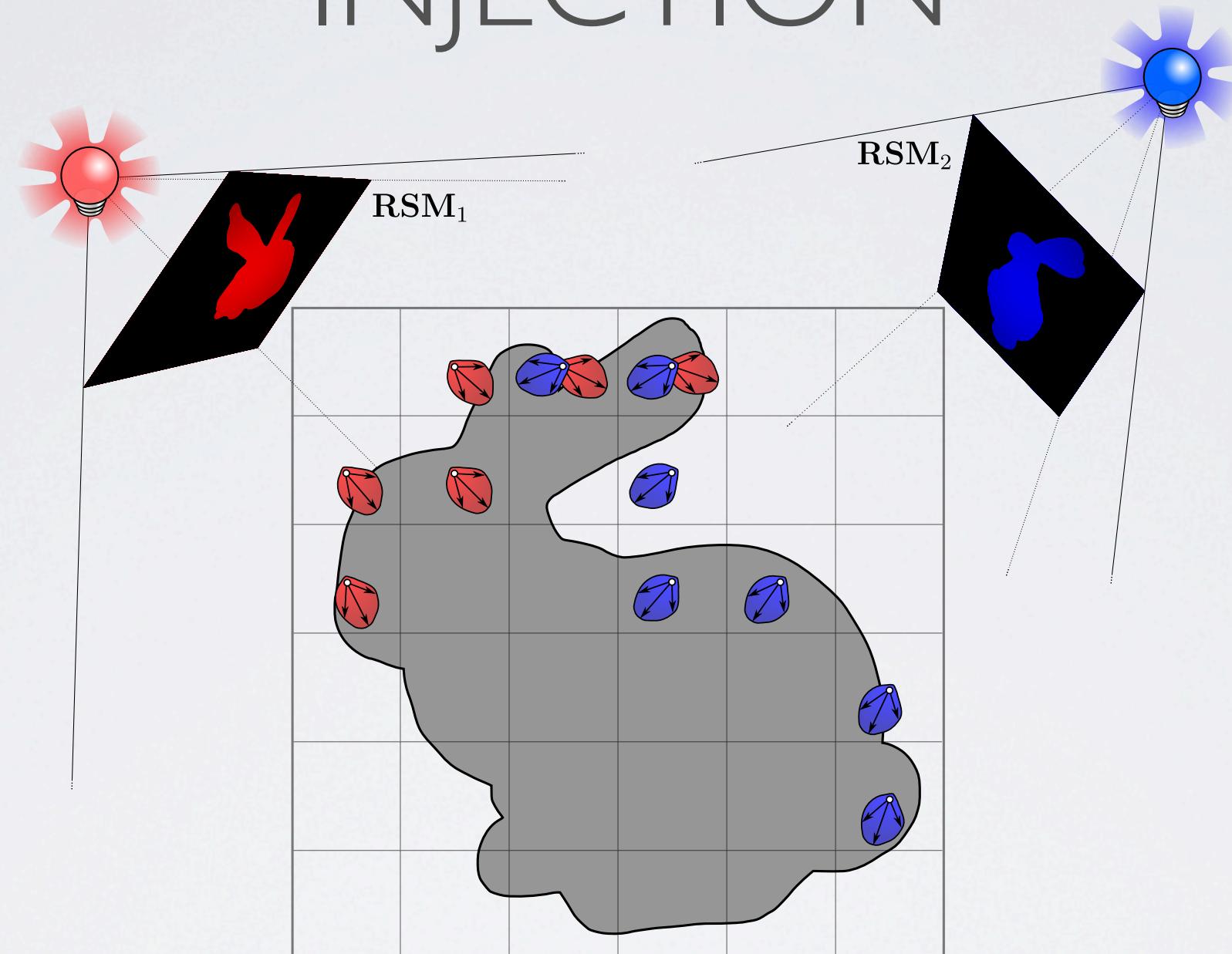
SHADOW MAPS



$$\Phi_p = I \Delta \omega_p$$

$$\Delta \omega_p \approx \frac{A_p \cos \theta_p}{\|\mathbf{r}_p\|^2} = \frac{4\alpha \tan^2(\frac{\text{FOV}}{2}) \cos^3 \theta_p}{N_x N_y}$$

INJECTION



$$I_p(\omega) = \frac{1}{\pi} T(\omega_p, \omega_t) \Phi_p \max\{0, \omega_t \cdot \omega\}$$

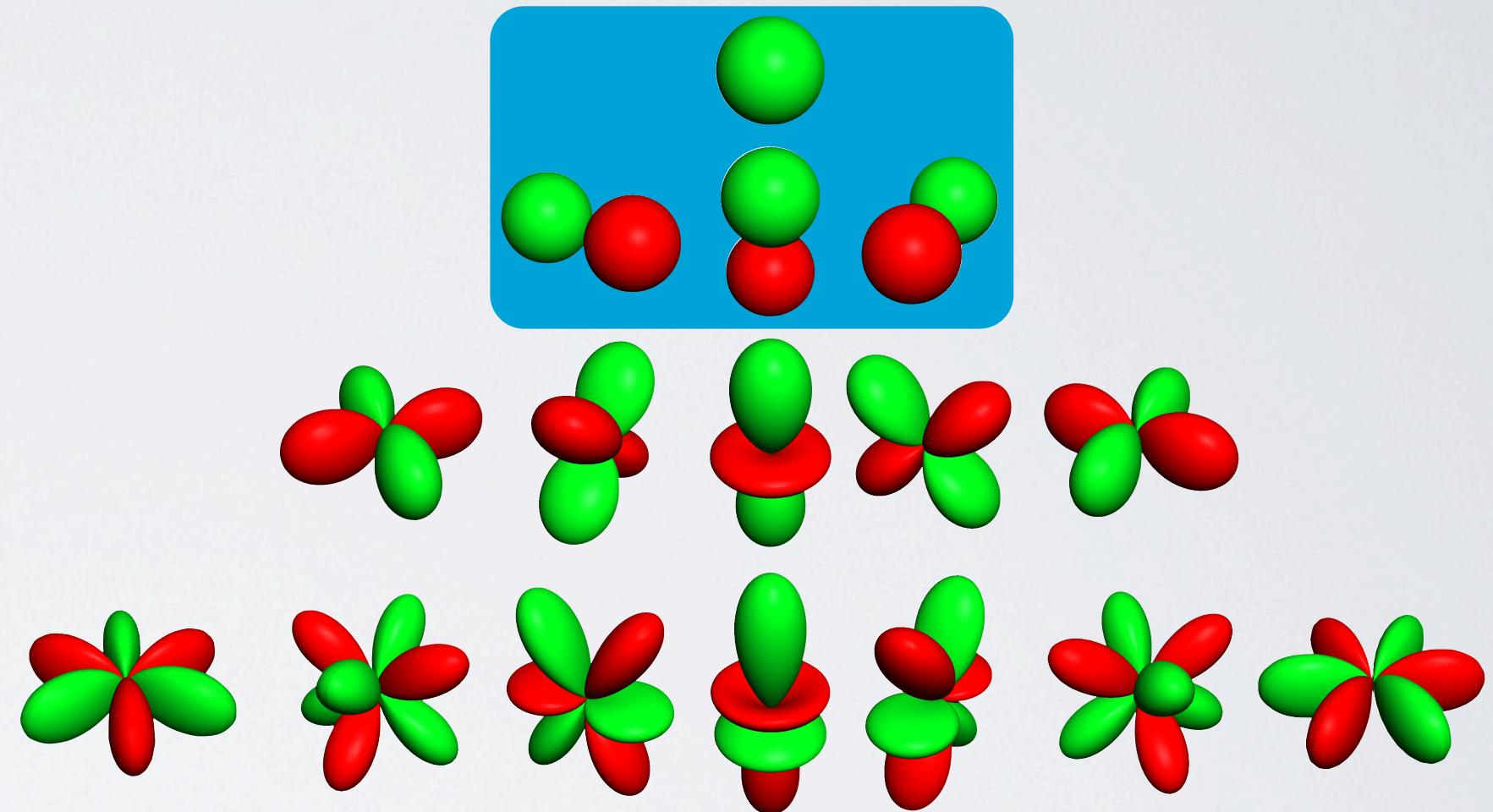
$$I(\omega) = \sum_{p, x_p \in \text{cell}} I_p(\omega)$$

SPHERICAL HARMONICS

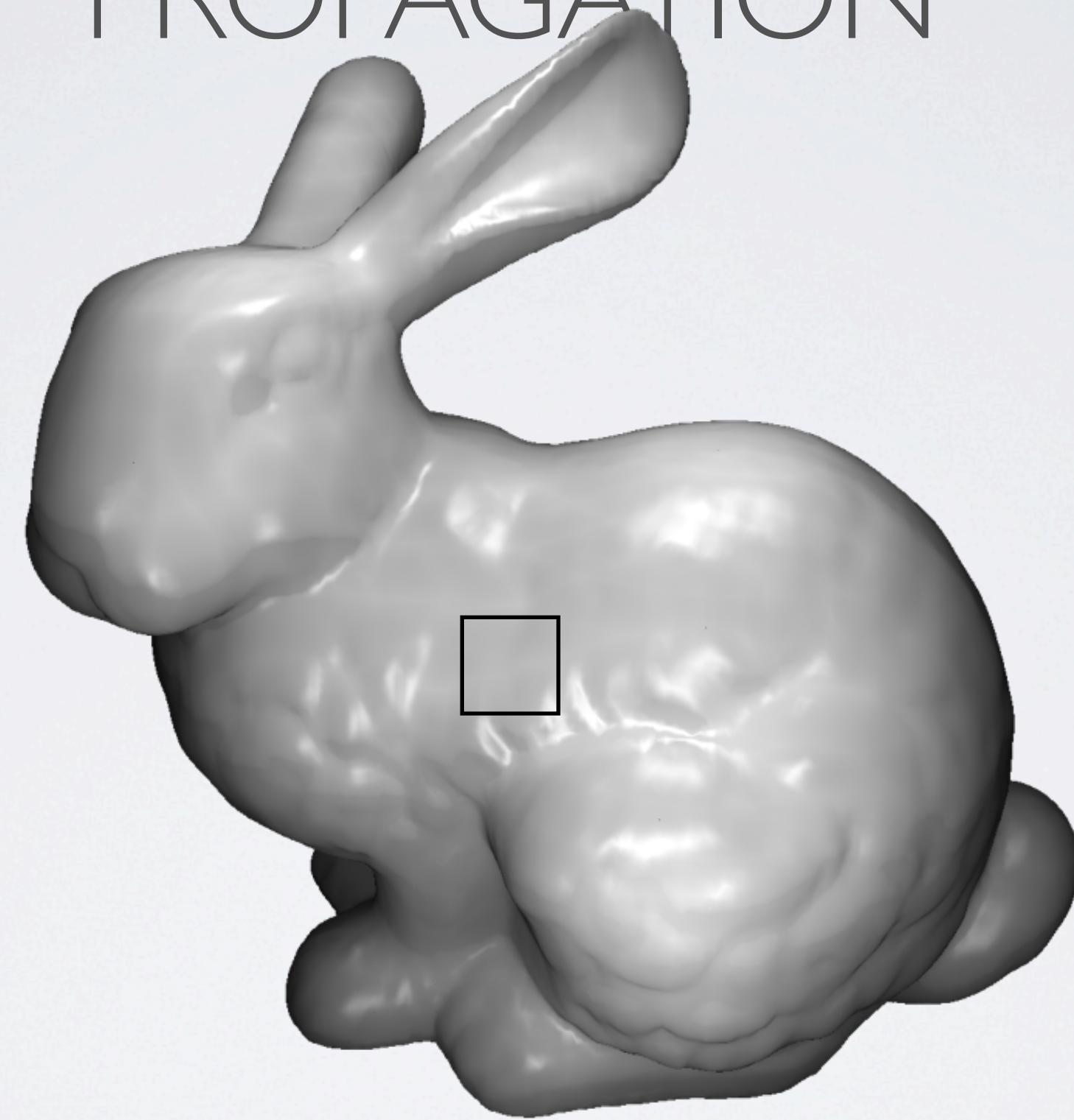
$$I(\omega) = \sum_{l=0}^{\infty} \sum_{m=-l}^l c_{lm} y_{lm}(\omega)$$

$$c_{lm} = \int_{4\pi} I(\omega) y_{lm}(\omega) d\omega$$

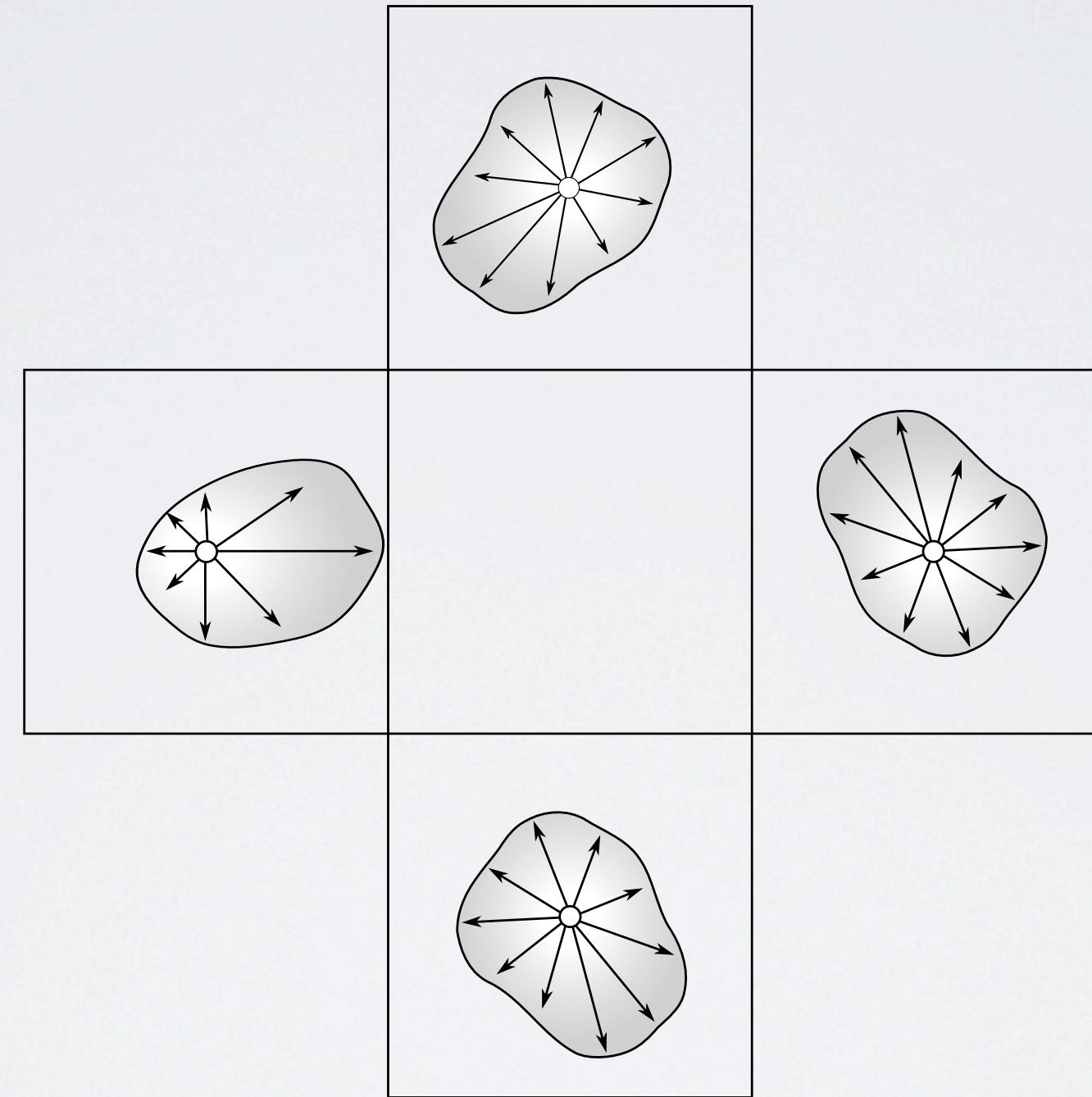
$$I(\omega) \approx c_{00} y_{00}(\omega) + c_{1-1} y_{1-1}(\omega) + c_{10} y_{10}(\omega) + c_{11} y_{11}(\omega)$$



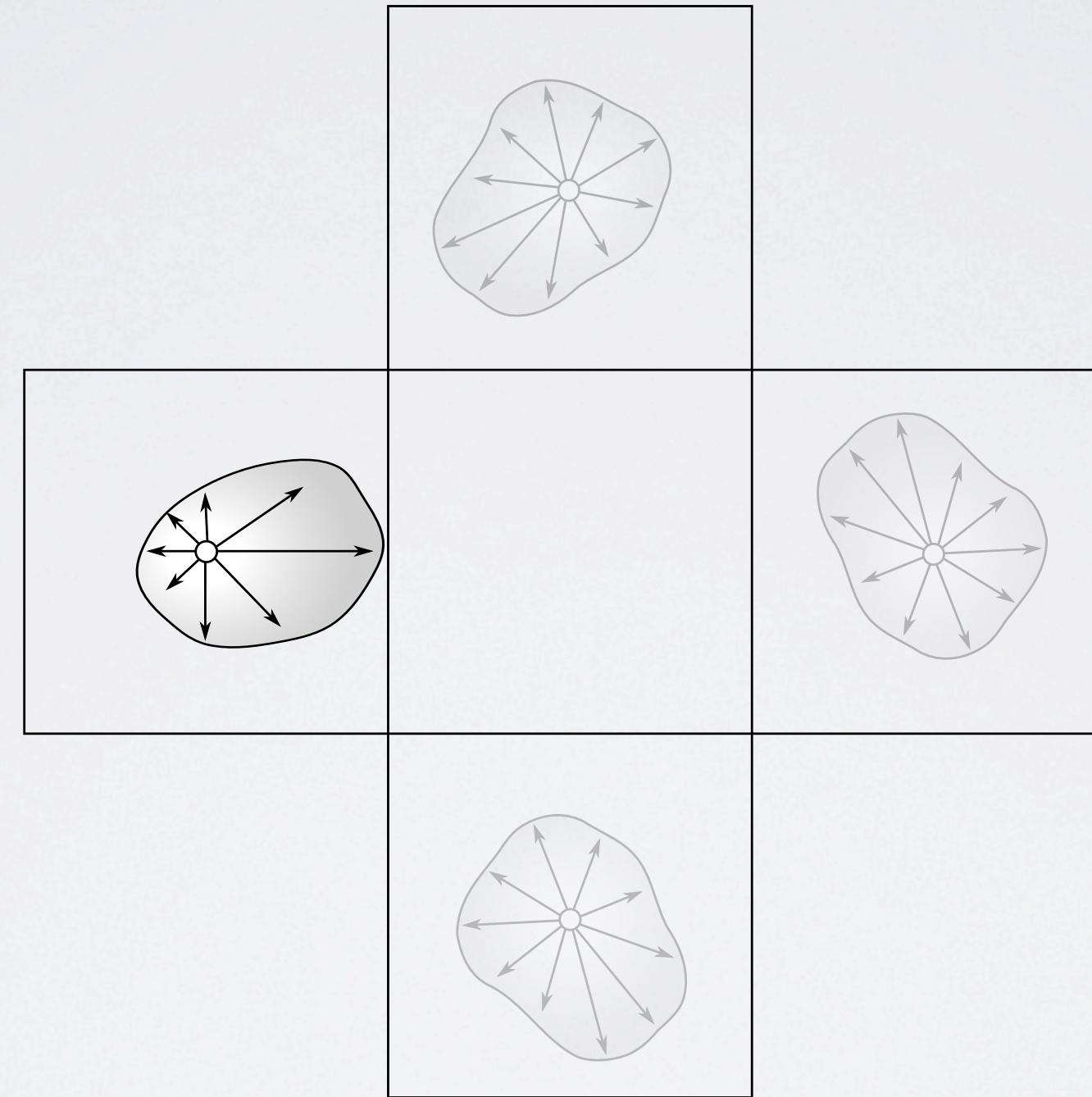
PROPAGATION



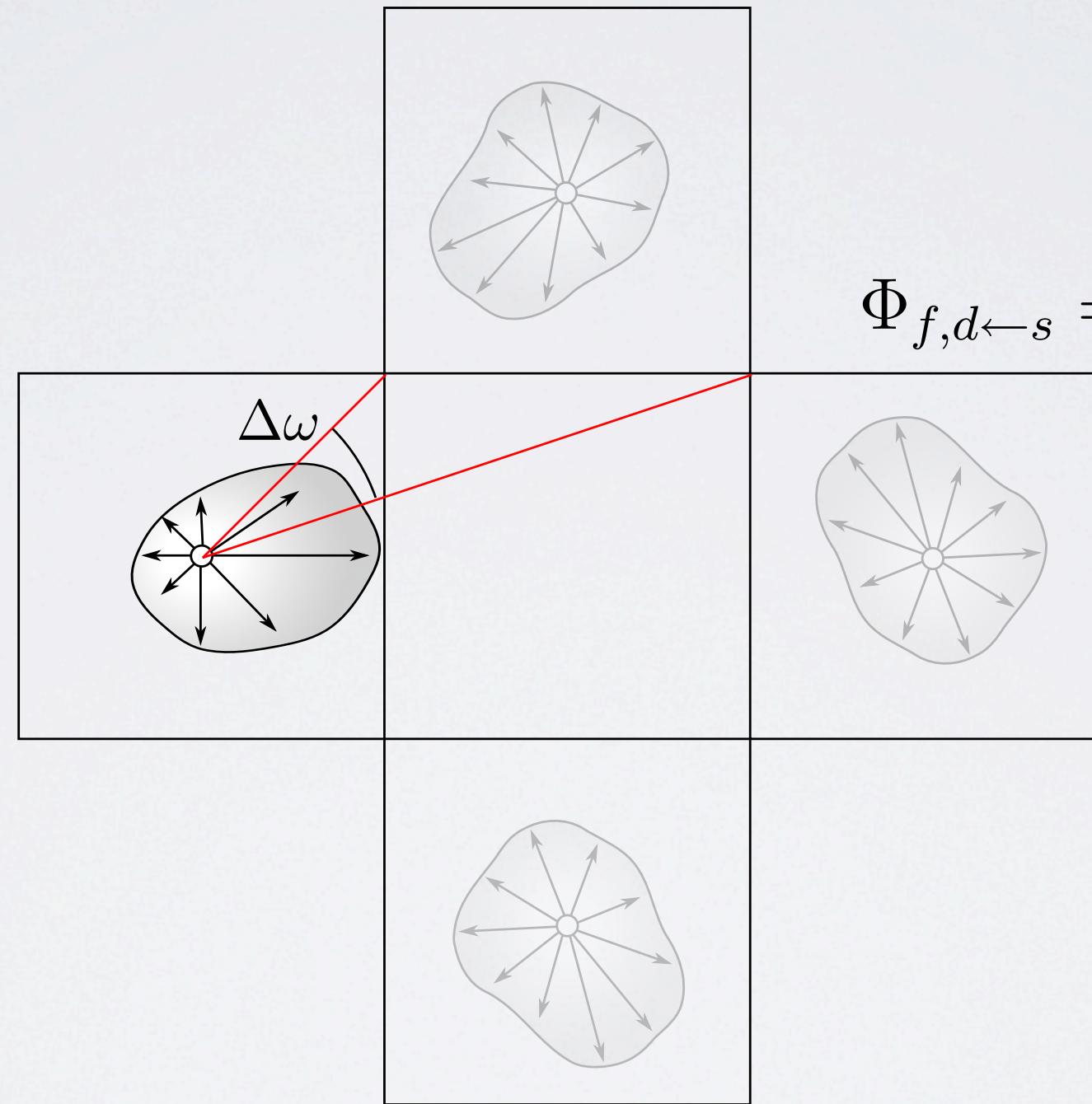
PROPAGATION



PROPAGATION

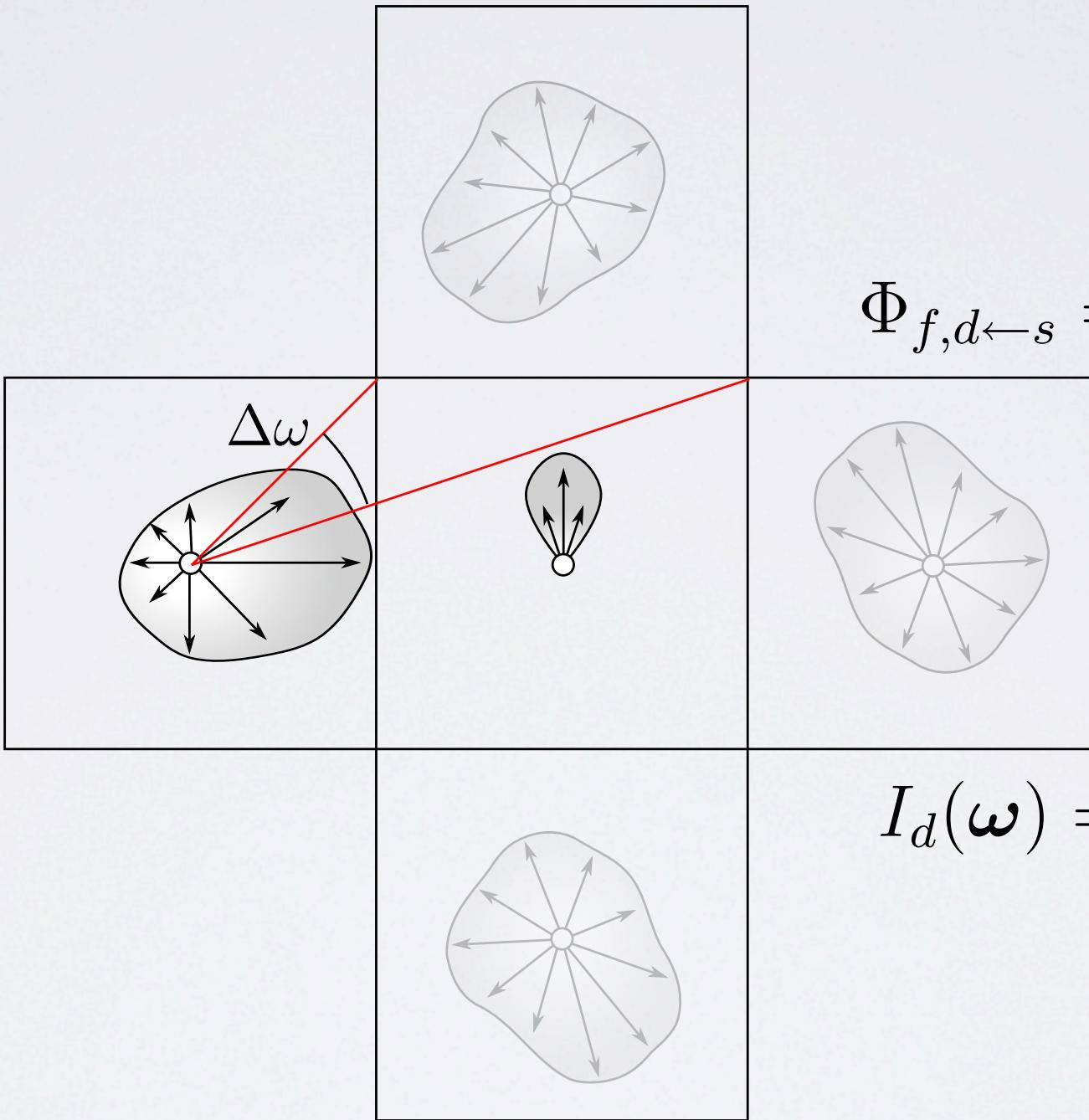


PROPAGATION



$$\Phi_{f,d \leftarrow s} = \int_{\Delta\omega} I_s(\omega) d\omega$$

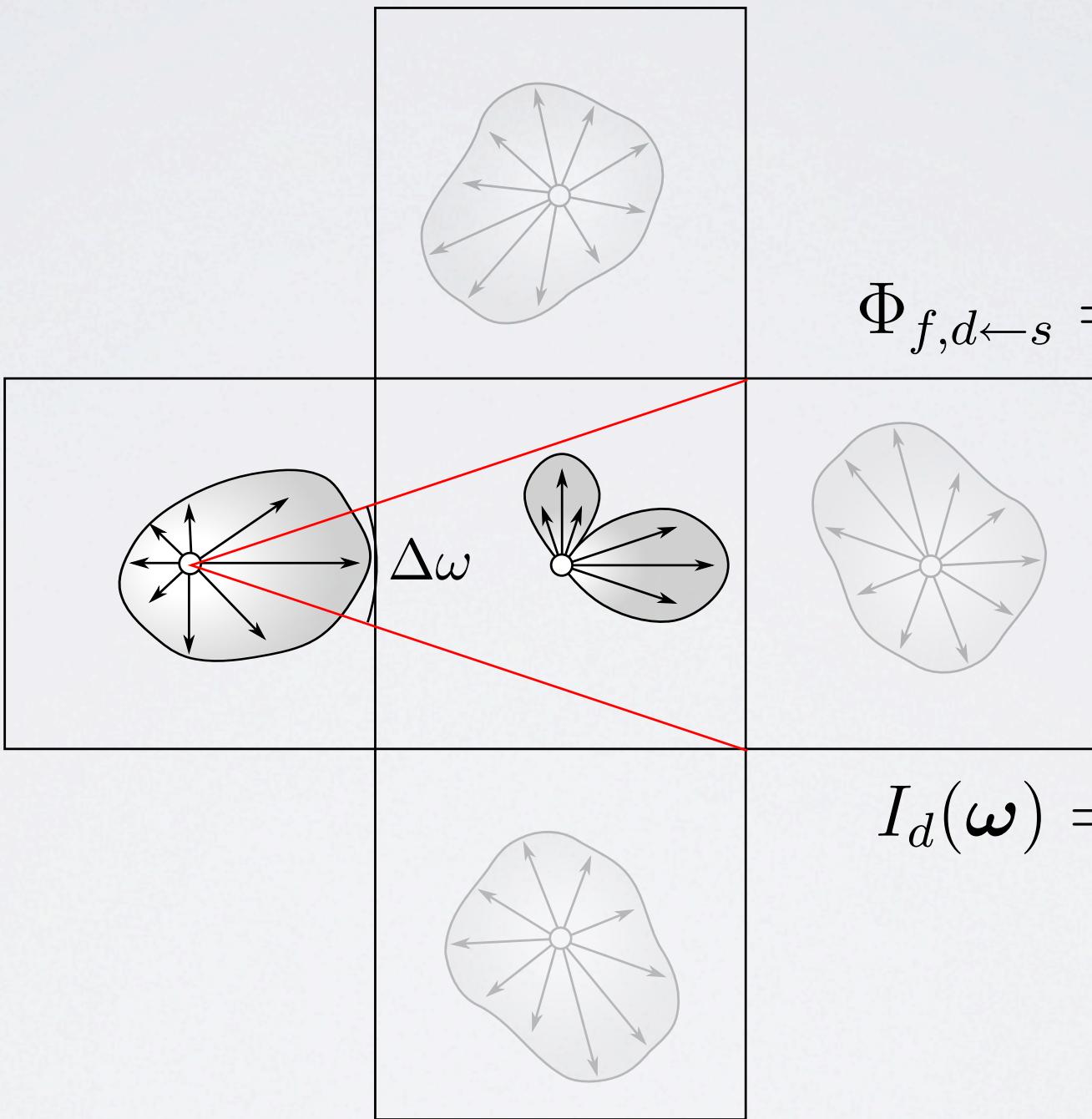
PROPAGATION



$$\Phi_{f,d \leftarrow s} = \int_{\Delta\omega} I_s(\omega) d\omega$$

$$I_d(\omega) = \frac{\Phi_{f,d \leftarrow s}}{\pi} \max(n_f \cdot \omega, 0)$$

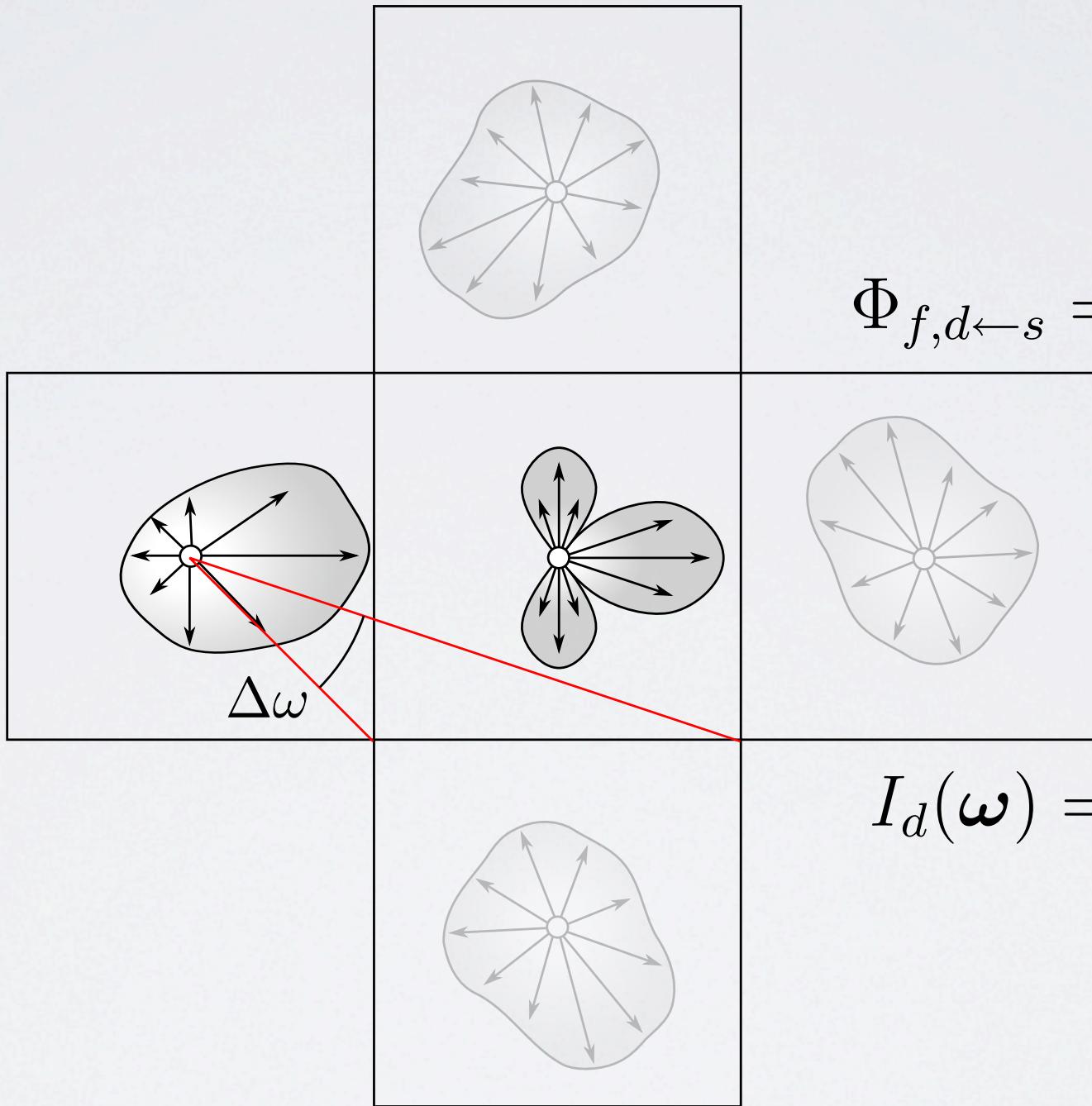
PROPAGATION



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PROPAGATION

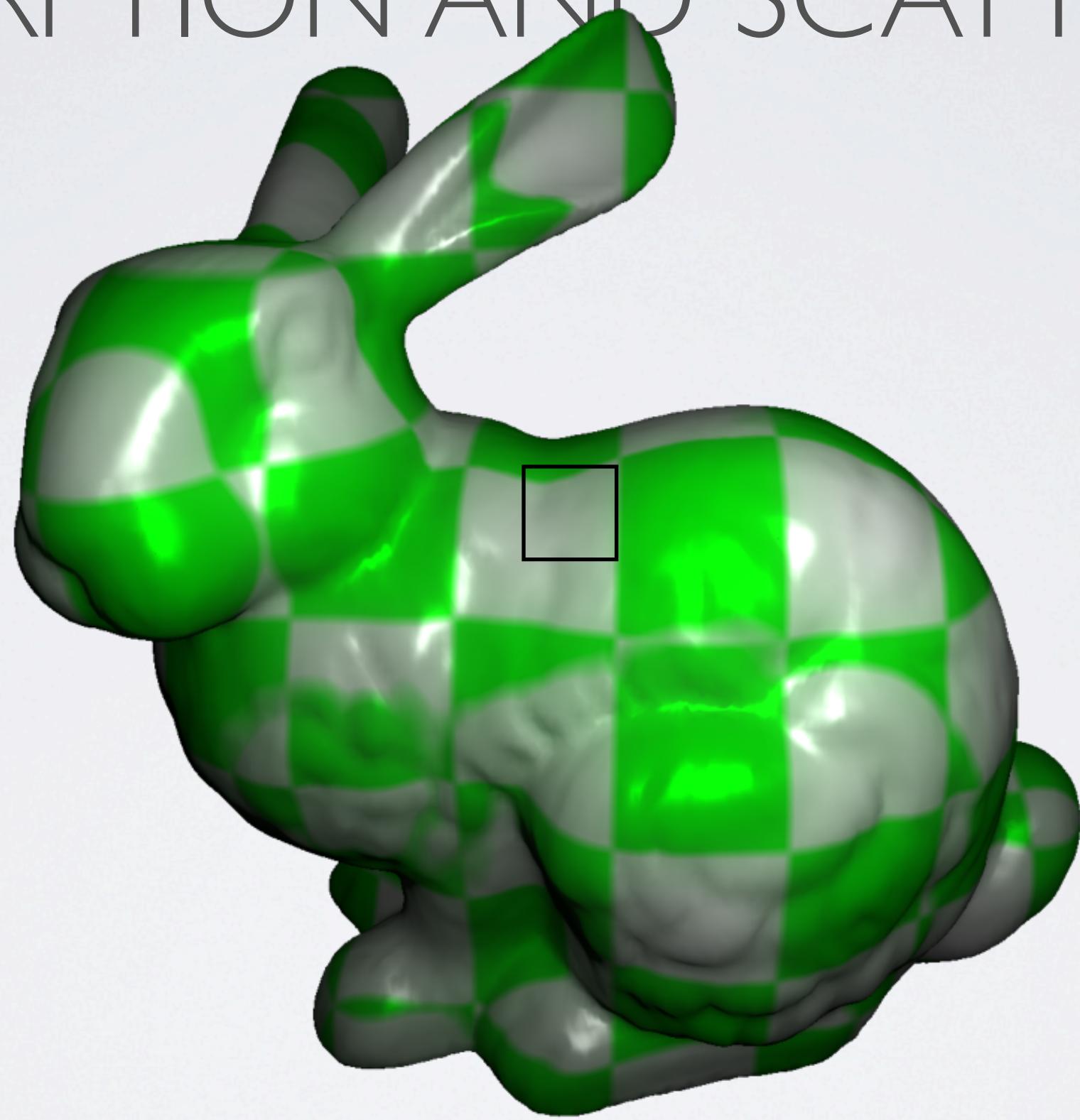


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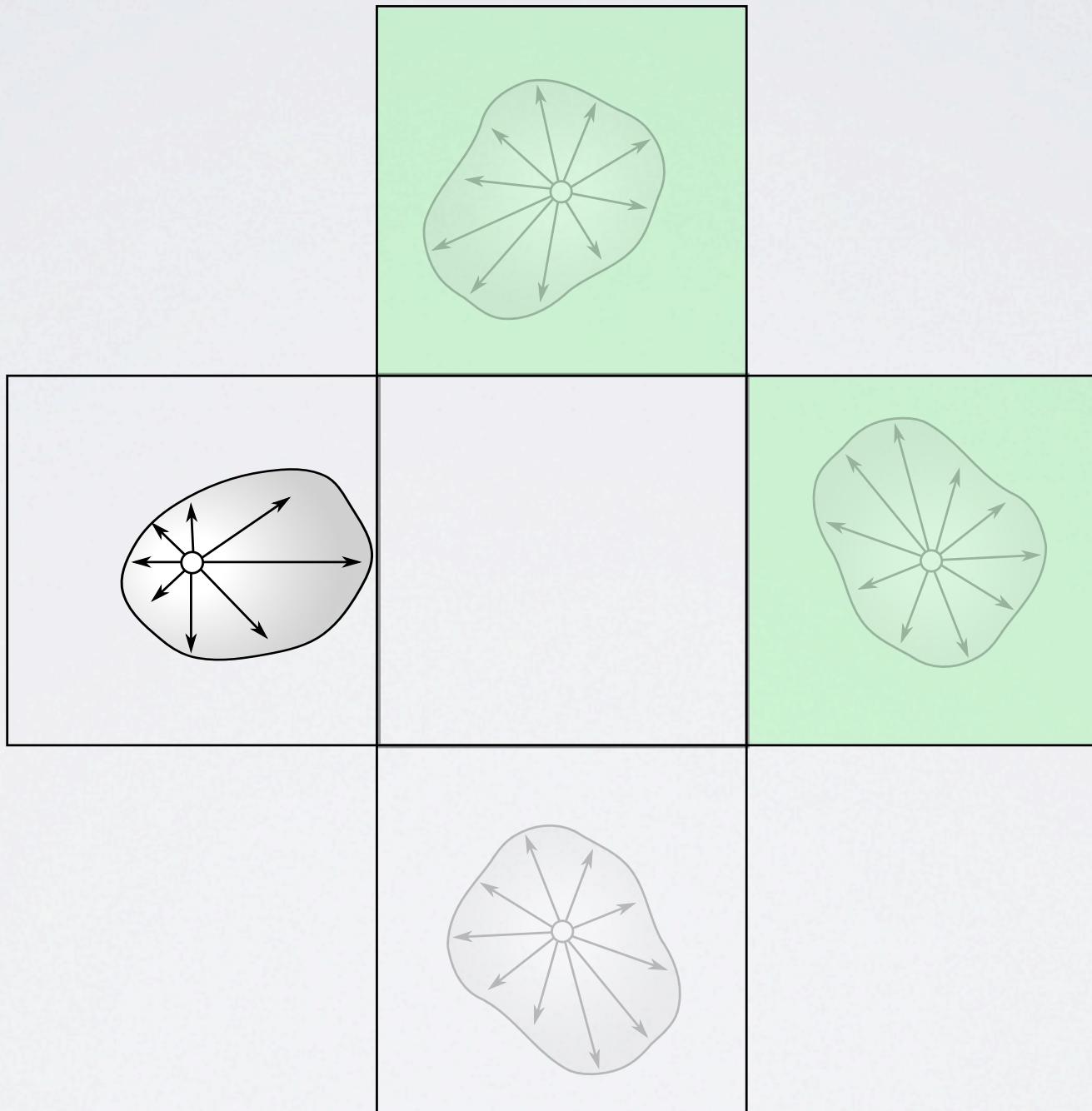
ABSORPTION AND SCATTERING

$\sigma_t(\mathbf{x}, \lambda)$
 $\sigma_s(\mathbf{x}, \lambda)$
 $p(\mathbf{x}, \lambda, \omega \cdot \omega')$



ABSORPTION AND SCATTERING

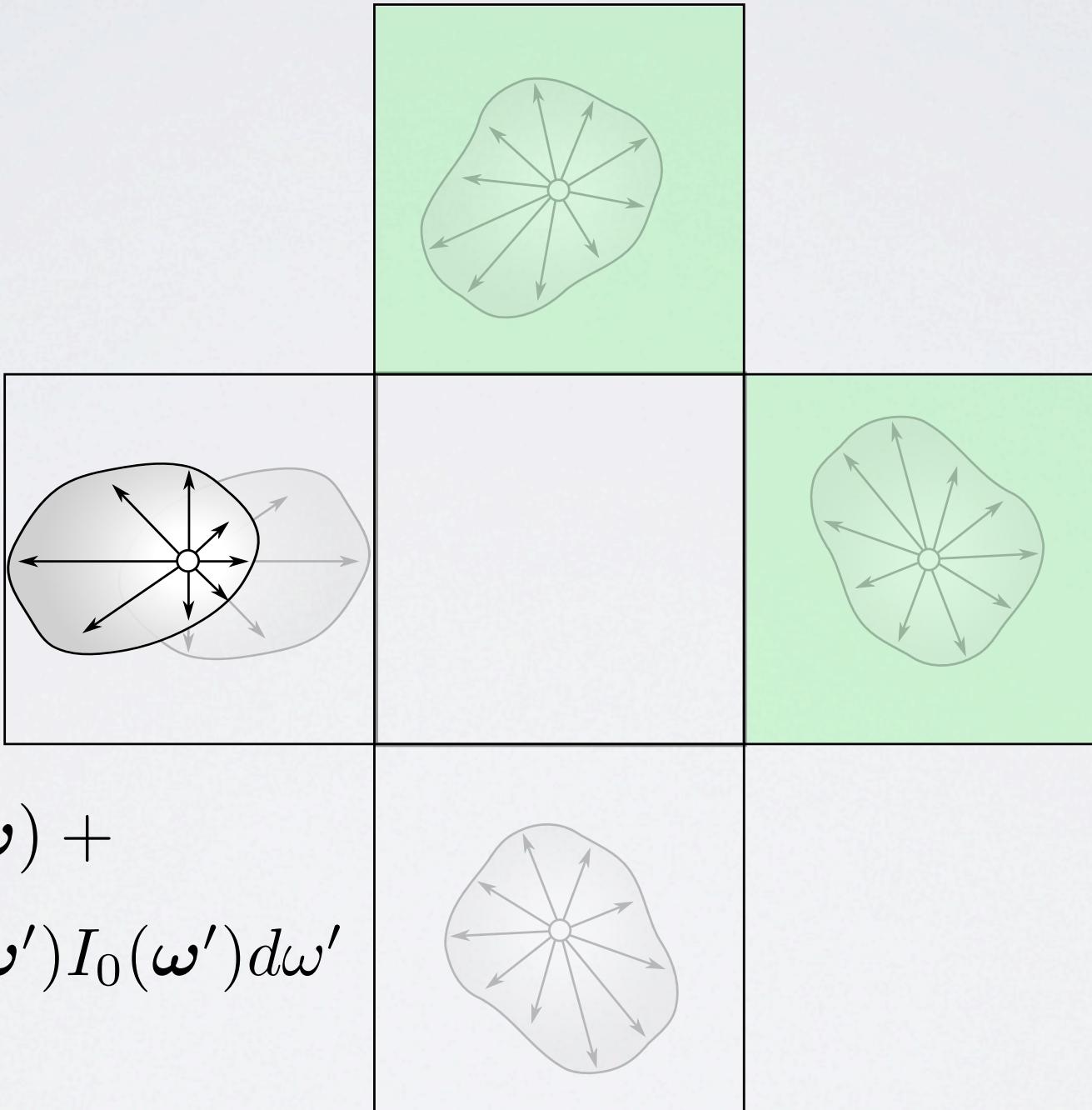
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ABSORPTION AND SCATTERING

$$\begin{aligned}\sigma_t(\mathbf{x}, \lambda) \\ \sigma_s(\mathbf{x}, \lambda) \\ p(\mathbf{x}, \lambda, \omega \cdot \omega')\end{aligned}$$

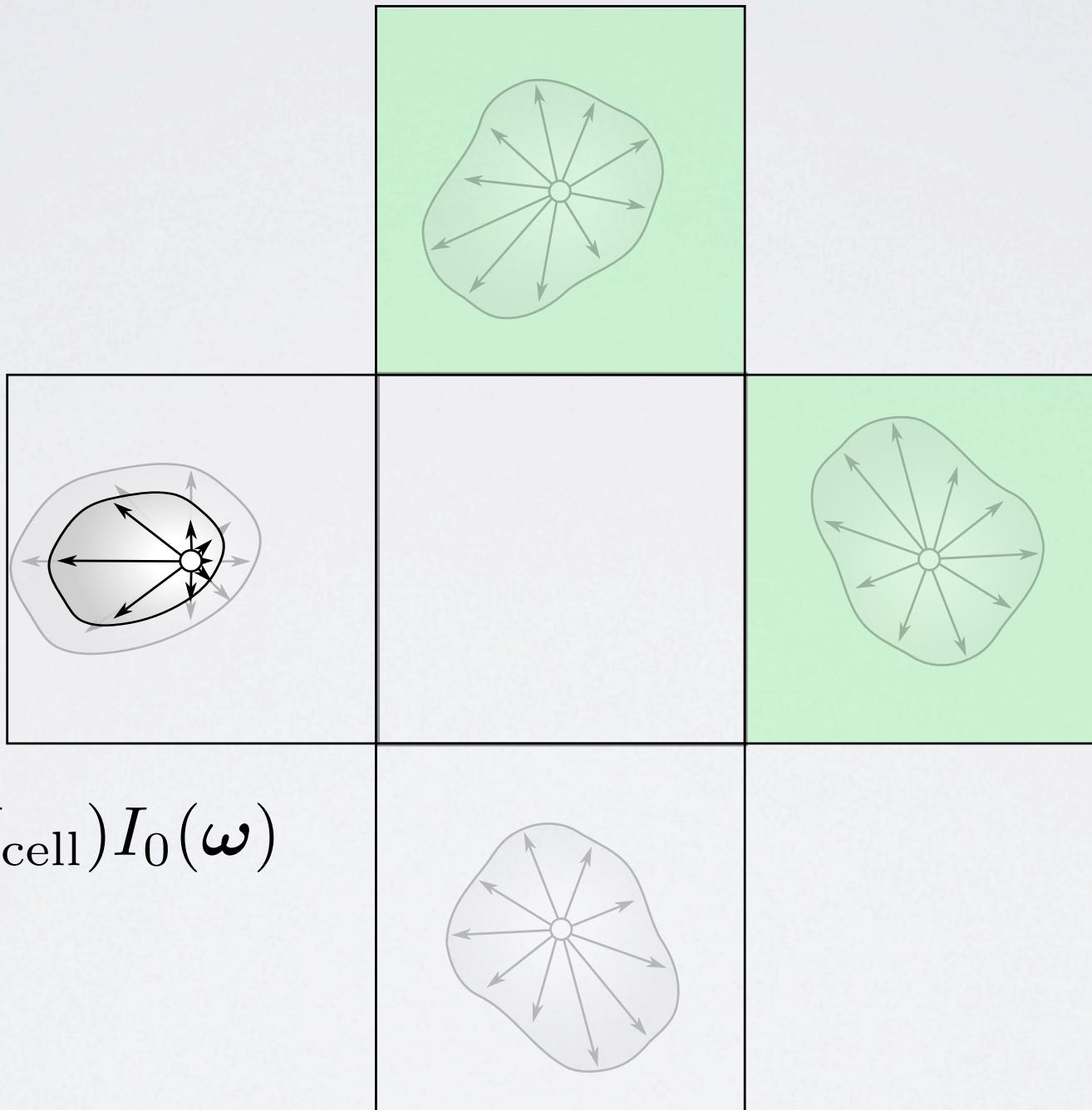
$$I(\omega) = (1 - \sigma'_s)I_0(\omega) + \sigma'_s \int_{4\pi} p(\omega \cdot \omega') I_0(\omega') d\omega'$$



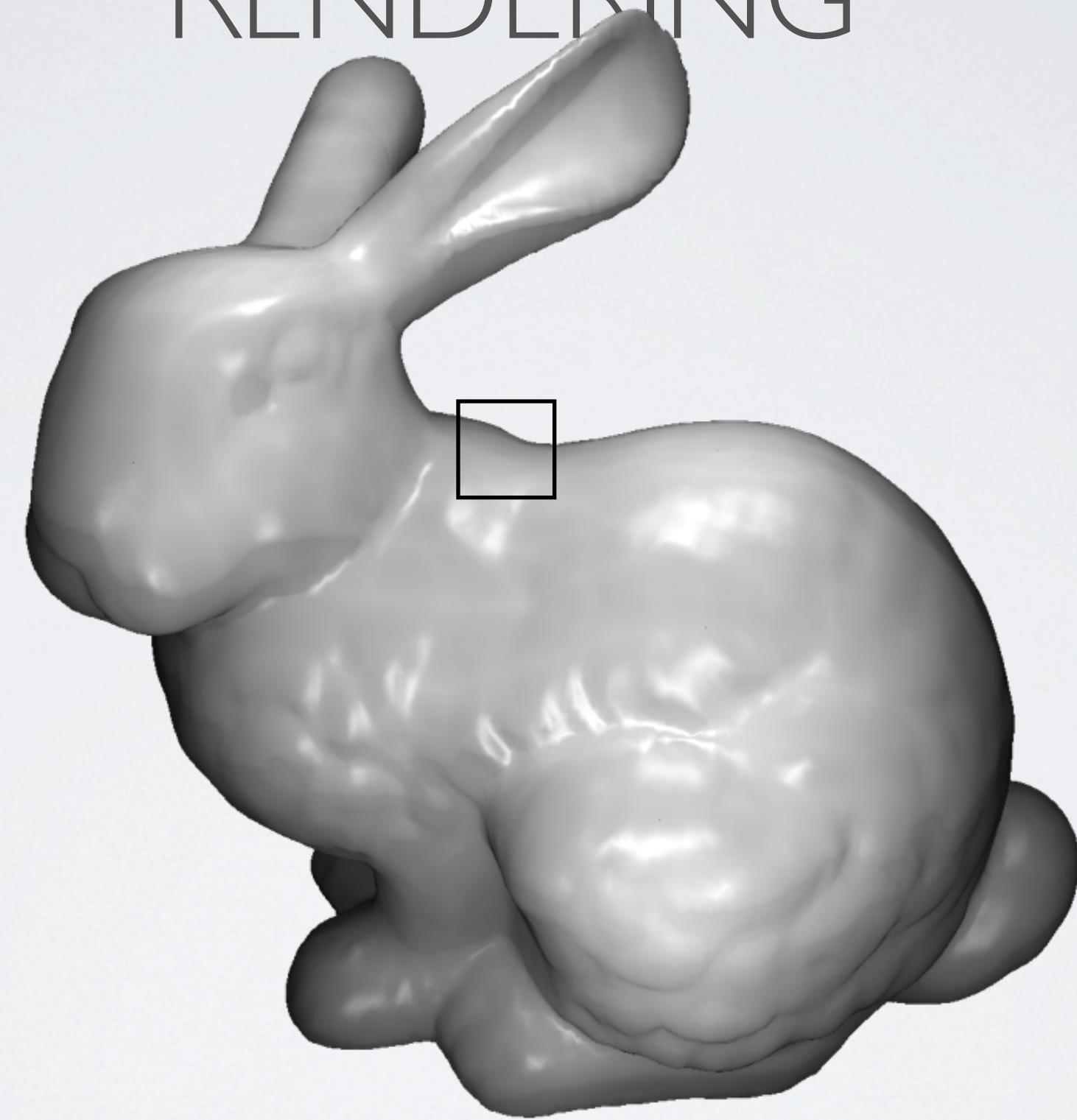
ABSORPTION AND SCATTERING

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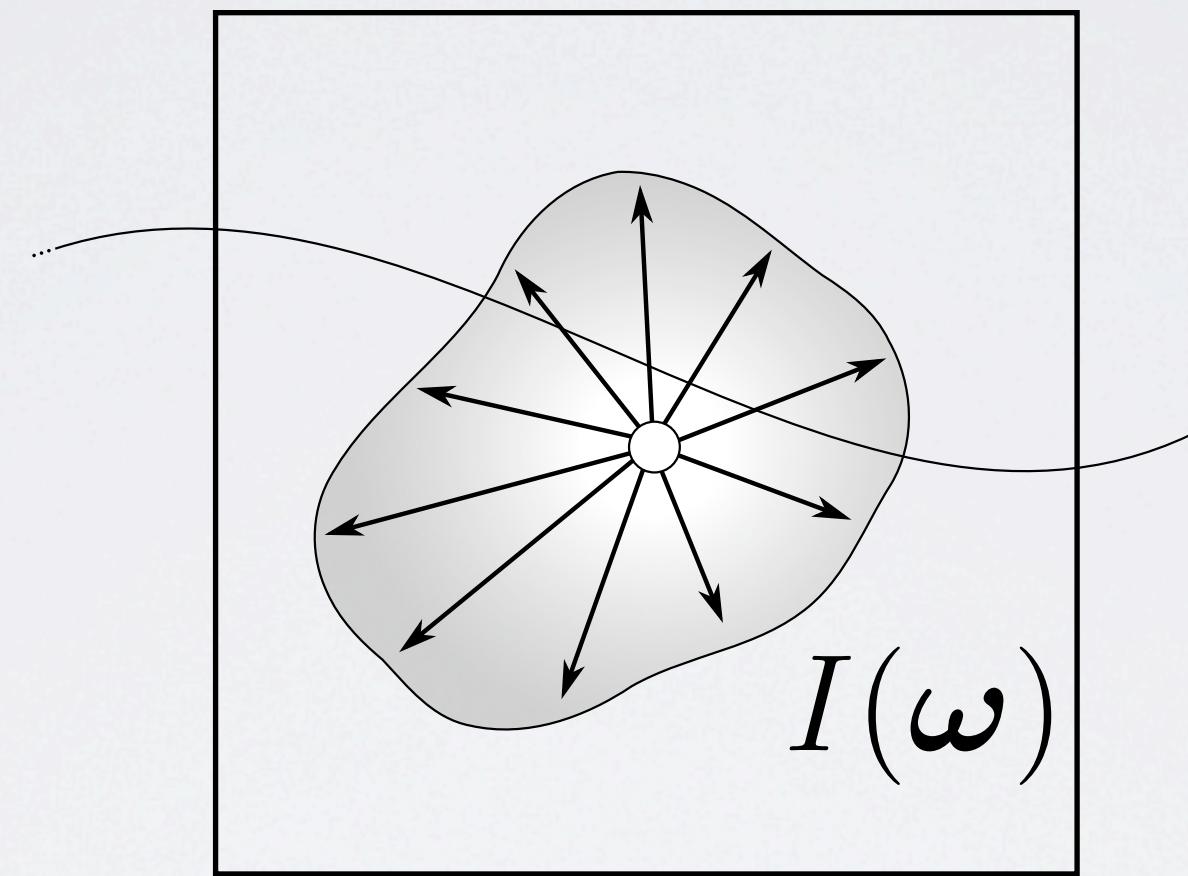
$$I(\omega) = \exp(-\sigma_t \Delta X_{\text{cell}}) I_0(\omega)$$



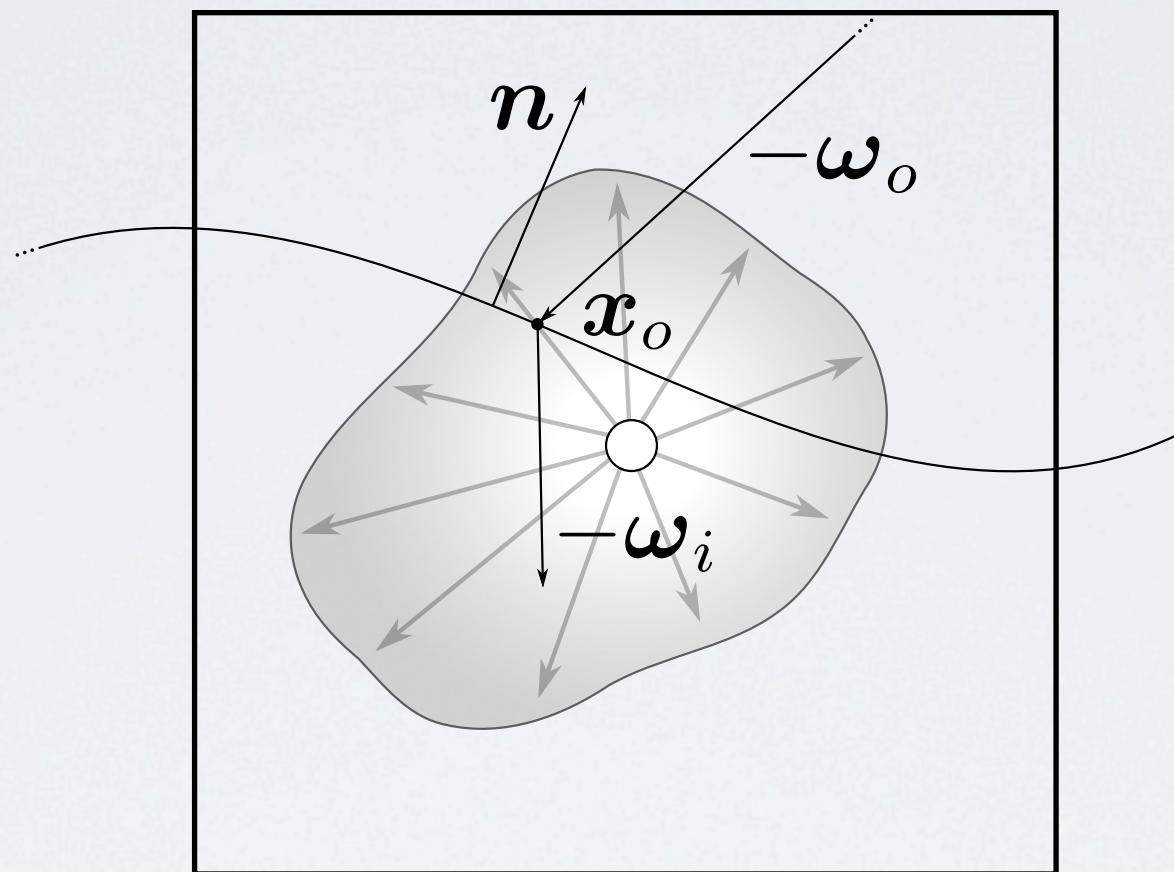
RENDERING



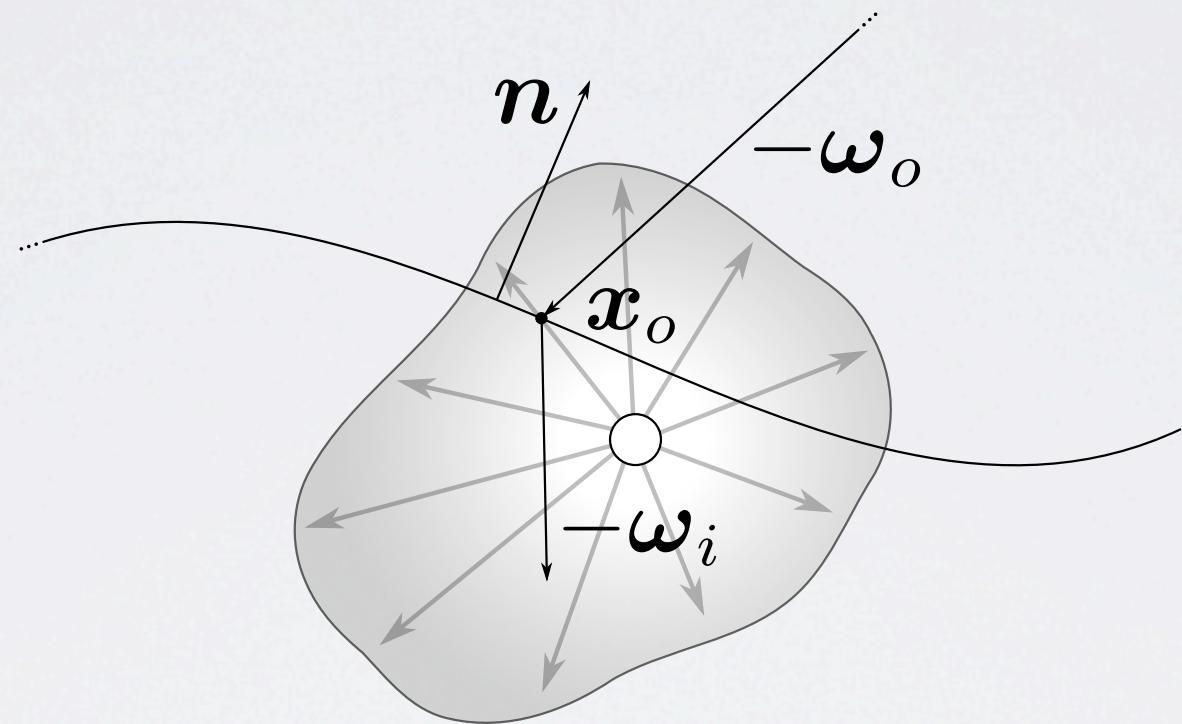
RENDERING



RENDERING

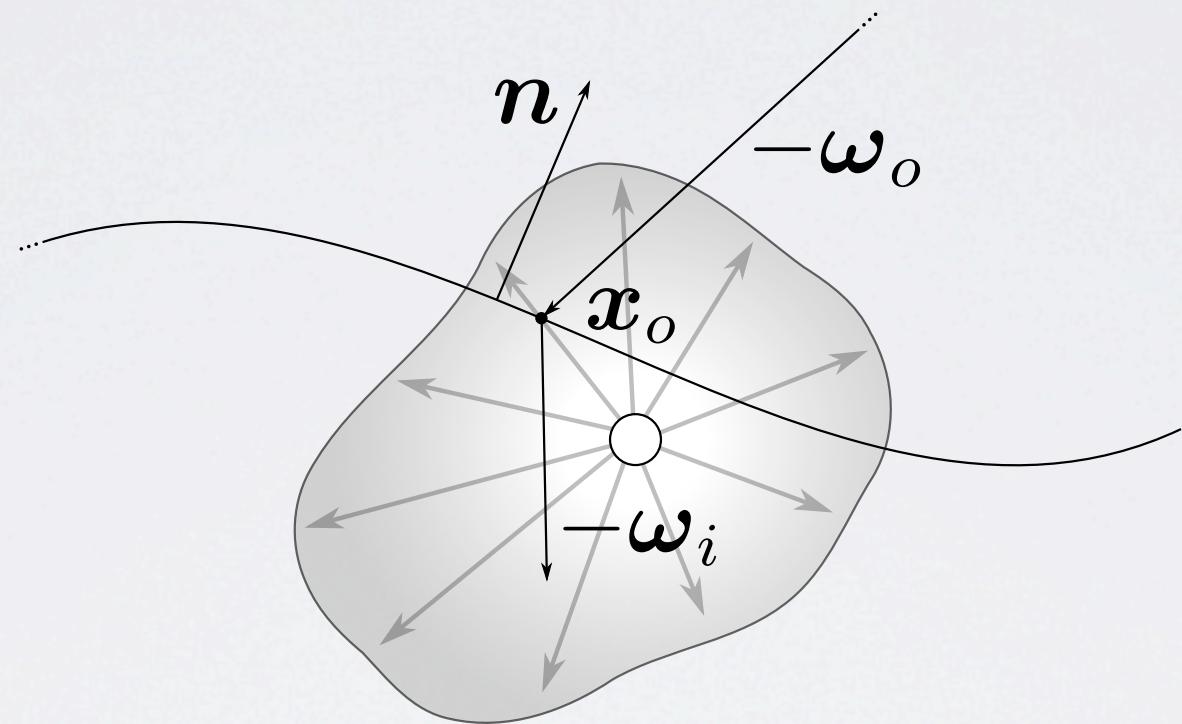


RENDERING



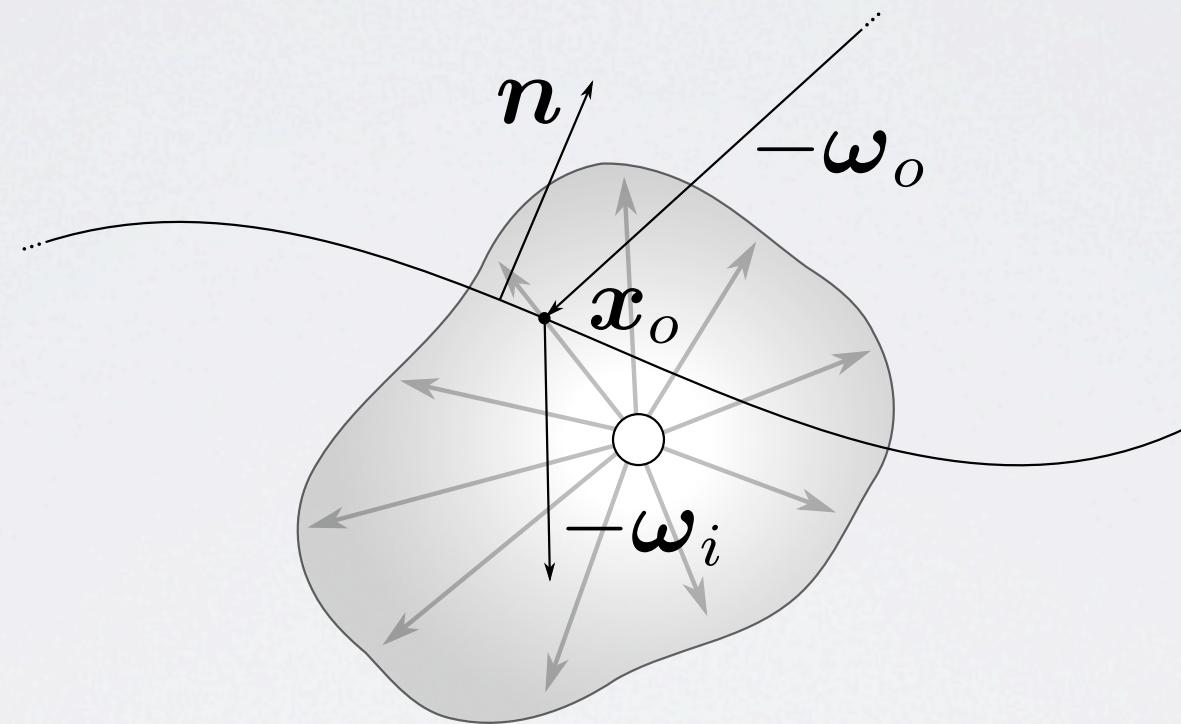
$$L_o(x_o, \omega_o) = T(\omega_i, \omega_o)L_i(x_o, \omega_i)$$

RENDERING



$$L_o(x_o, \omega_o) = T(\omega_i, \omega_o) L_i(x_o, \omega_i)$$

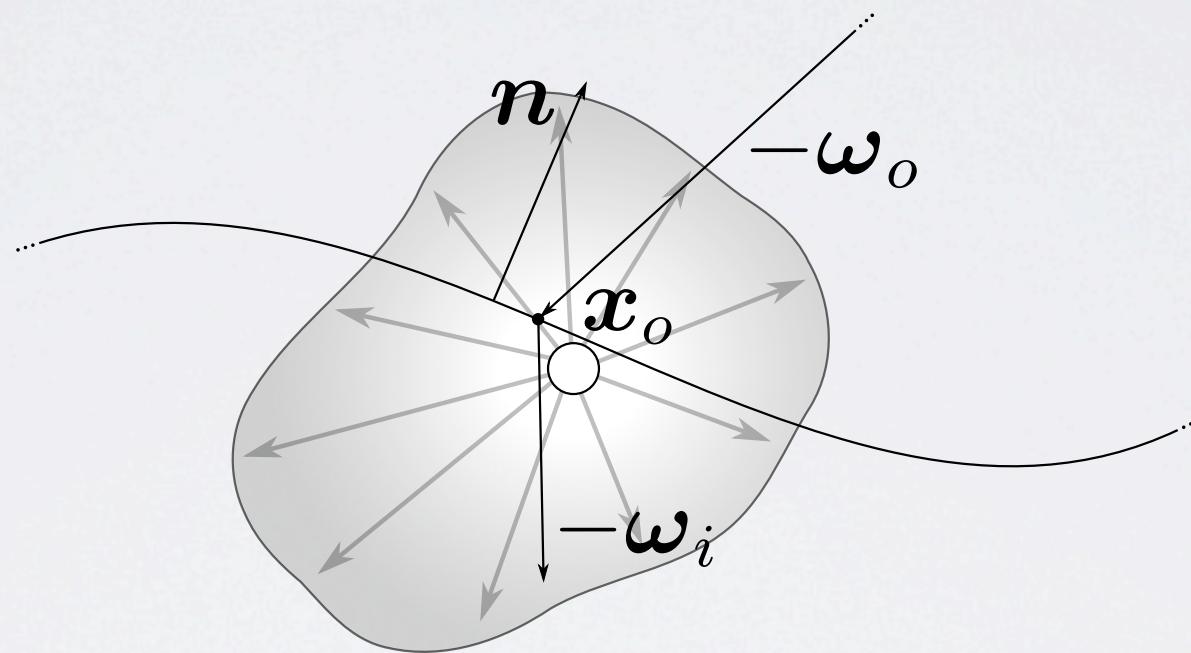
RENDERING



$$L_o(x_o, \omega_o) = T(\omega_i, \omega_o) L_i(x_o, \omega_i)$$

$$L_i(x_o, \omega) = \frac{I(\omega)}{|x_o - x_{\text{VPL}}|^2}$$

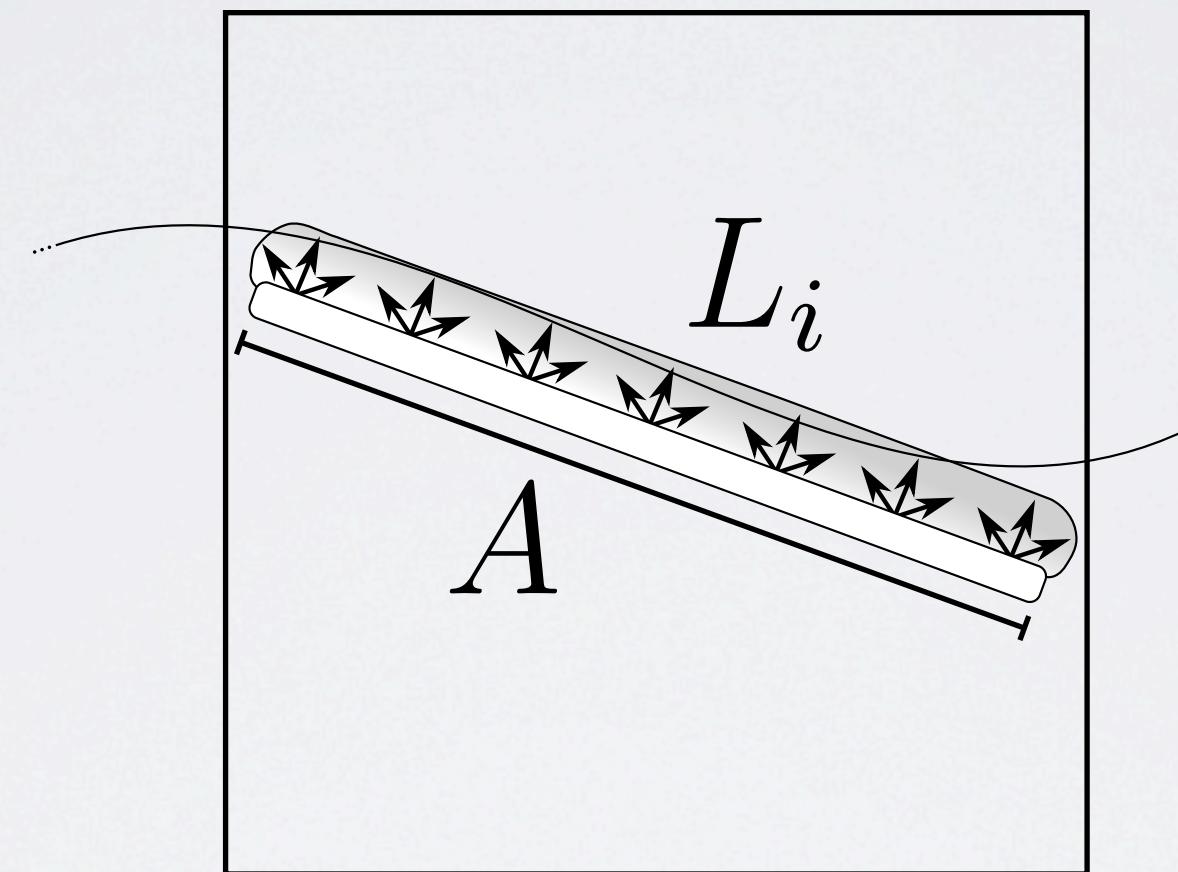
RENDERING



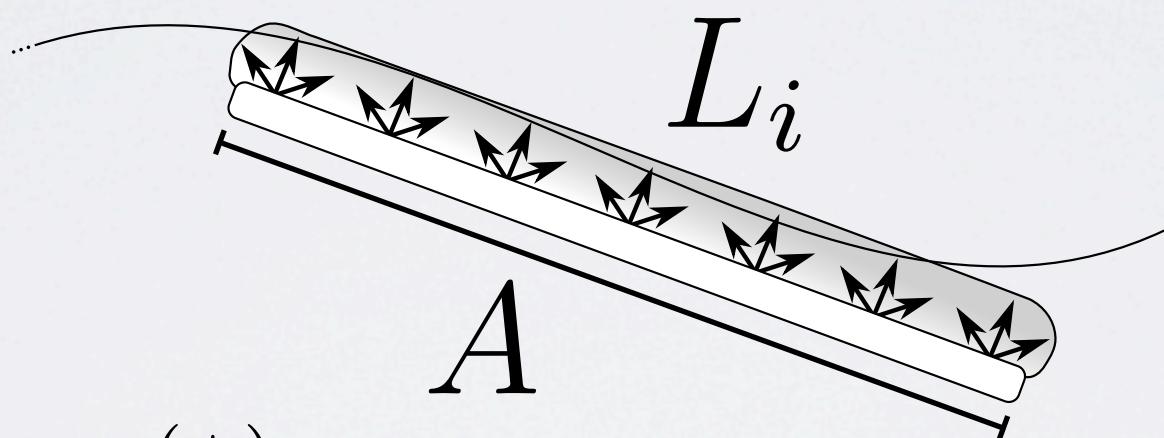
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RENDERING



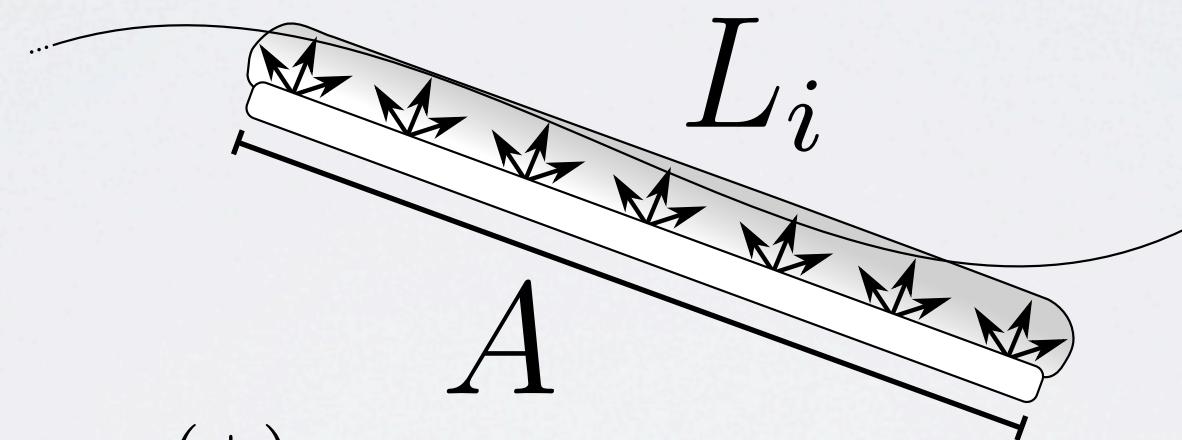
RENDERING



$$L_i = \frac{\Phi_{area}}{A\pi} = \frac{\Phi_{point}^{(+)}}{A\pi} \quad \Phi_{point}^{(+)} = \int_{2\pi, n \cdot \omega > 0} I(\omega) d\omega$$

$$L_i = \frac{1}{A\pi} \int_{2\pi, n \cdot \omega > 0} I(\omega) d\omega$$

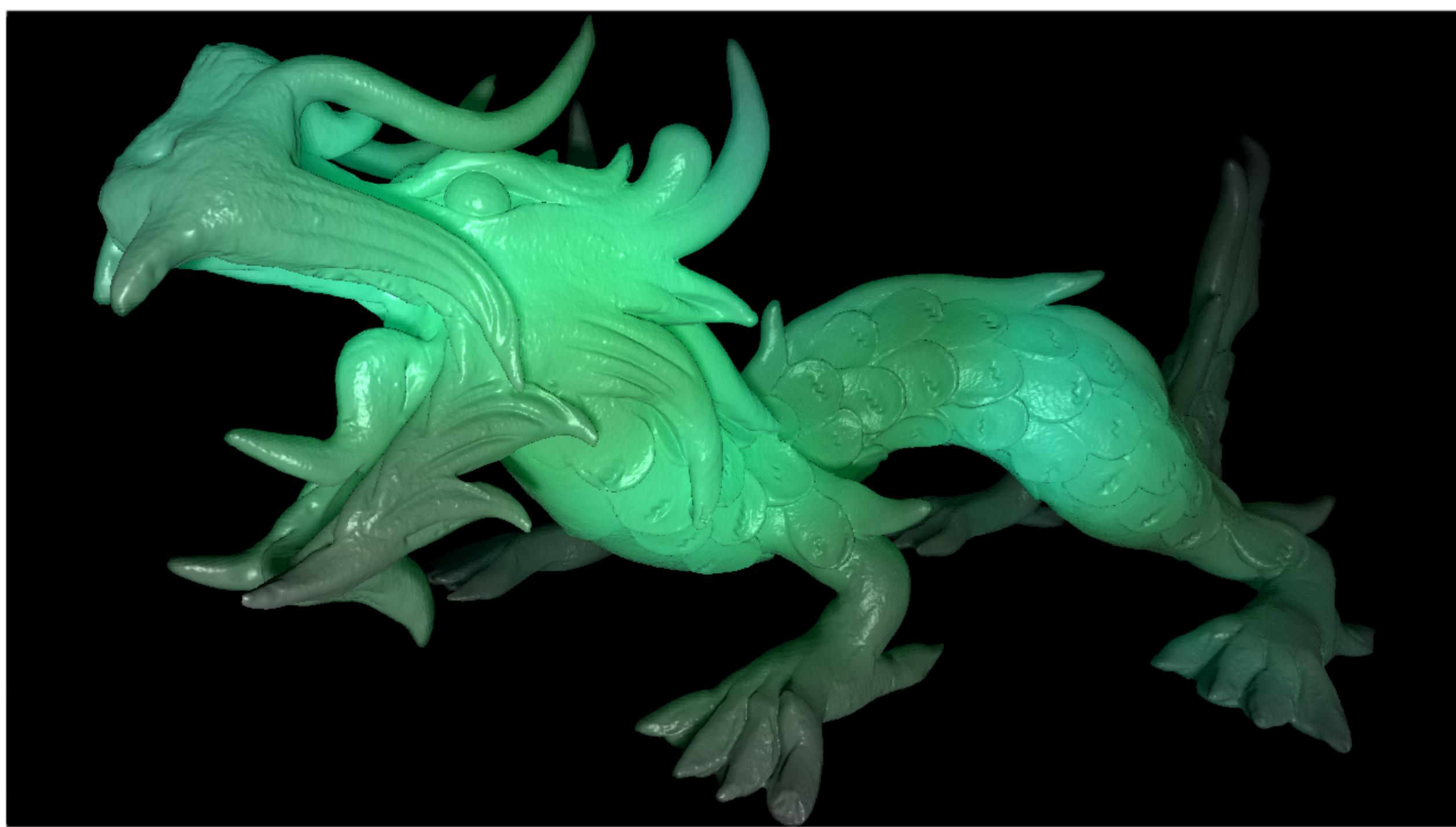
RENDERING



$$L_i = \frac{\Phi_{area}}{A\pi} = \frac{\Phi_{point}^{(+)}}{A\pi} \quad \Phi_{point}^{(+)} = \int_{2\pi, \mathbf{n} \cdot \boldsymbol{\omega} > 0} I(\boldsymbol{\omega}) d\boldsymbol{\omega}$$

$$L_i = \frac{1}{A\pi} \sum_{l,m} c_{lm} \int_{2\pi, \mathbf{n} \cdot \boldsymbol{\omega} > 0} y_{lm}(\boldsymbol{\omega}) d\boldsymbol{\omega}$$

RESULTS

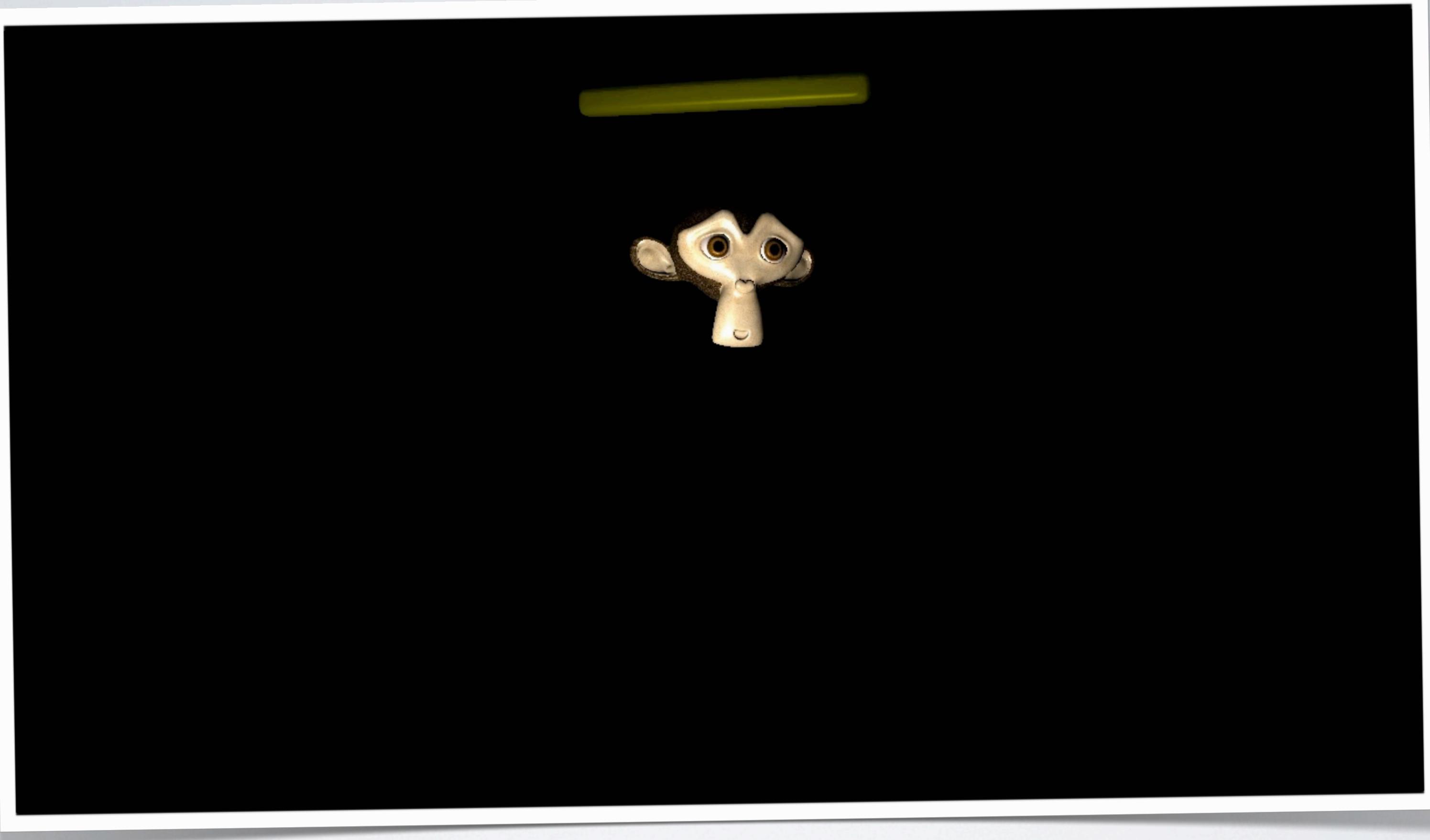


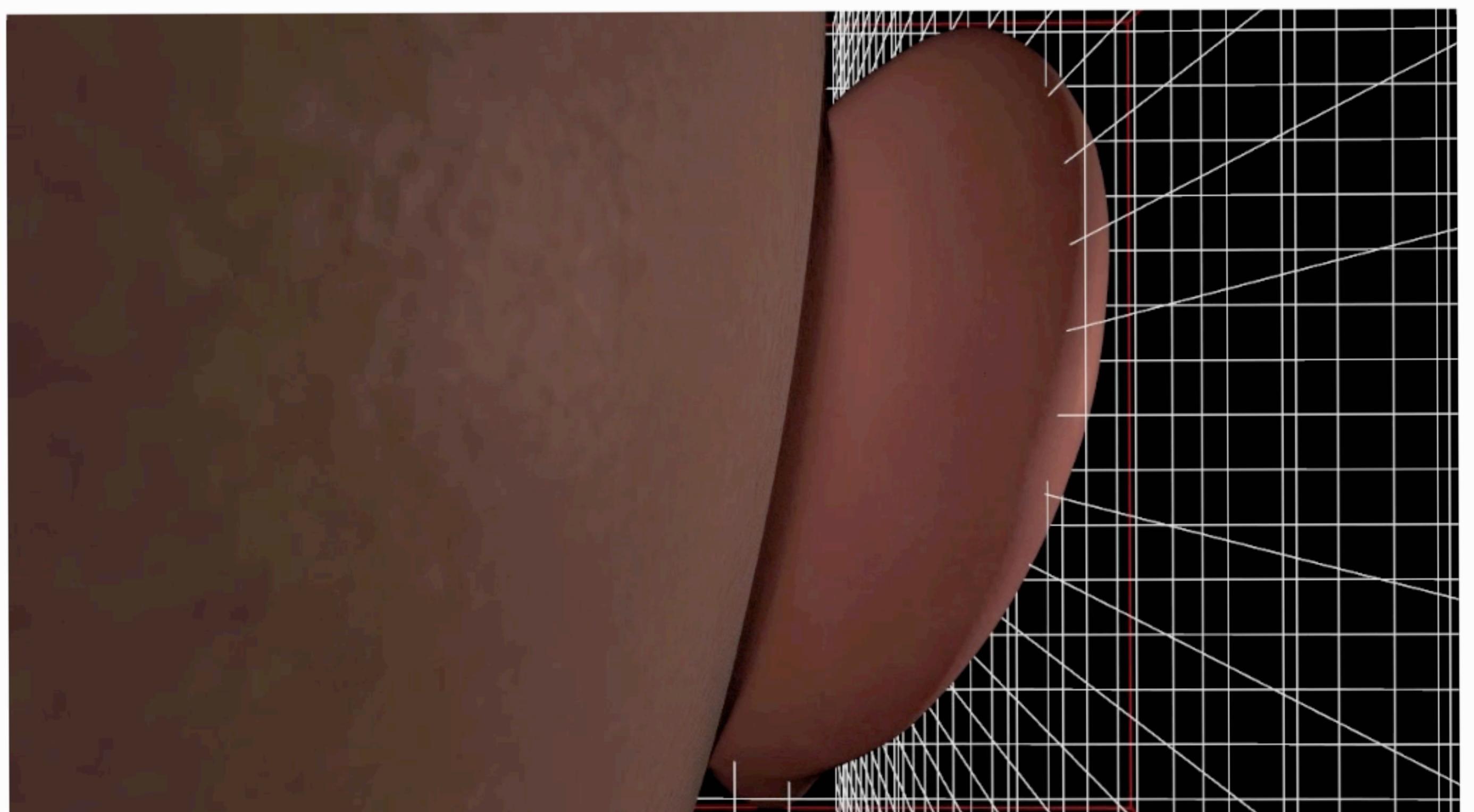
RESULTS





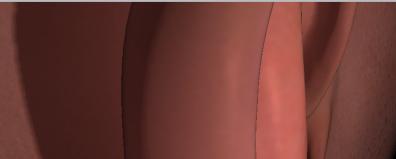






Comparison of quality at different LPV grid resolutions

TIMINGS

Model	Number of triangles	Lights / Grid resolution	Average Timings (ms)				
			RSM	Injection	Propagation	Shading	Total
	7.2M	1 / 32^3	5.91	0.13	2.72	5.94	14.7
	32K	1 / 32^3	0.30	0.30	0.72	0.48	1.8
	Max. 110K	1 / 32^3	0.17	0.29	0.72	0.13	1.32
	323K	1 / 32^3	0.45	0.12	1.66	0.39	2.23
		2 / 64^3	0.94	0.27	3.77	0.87	5.85

256^2 shadow maps - 8 propagation steps

LIMITATIONS

- Not well-suited for modeling highly translucent materials
- Grid artifacts can occur when using low resolution LPV grid
- Temporal flickering can occur when using low resolution shadow maps

FUTURE WORK

- Introduce blocking potentials
- Extend to cascaded LPV grids
- Explore using tetrahedral mesh instead of a grid
- Extend to more spherical harmonics bands

CONCLUSION

- Visually plausible results in real-time
- Requires no pre-computation
- Handles arbitrarily deforming meshes
- Supports heterogeneous materials

THANK YOU!

<http://cg.alexandra.dk>

