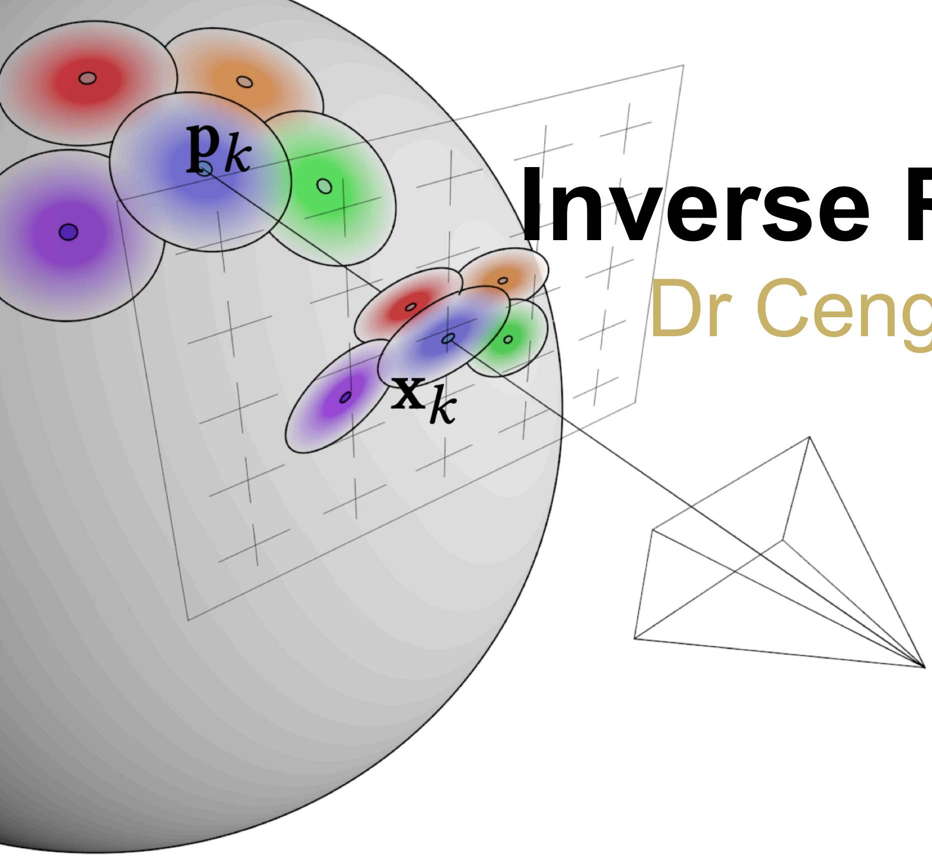
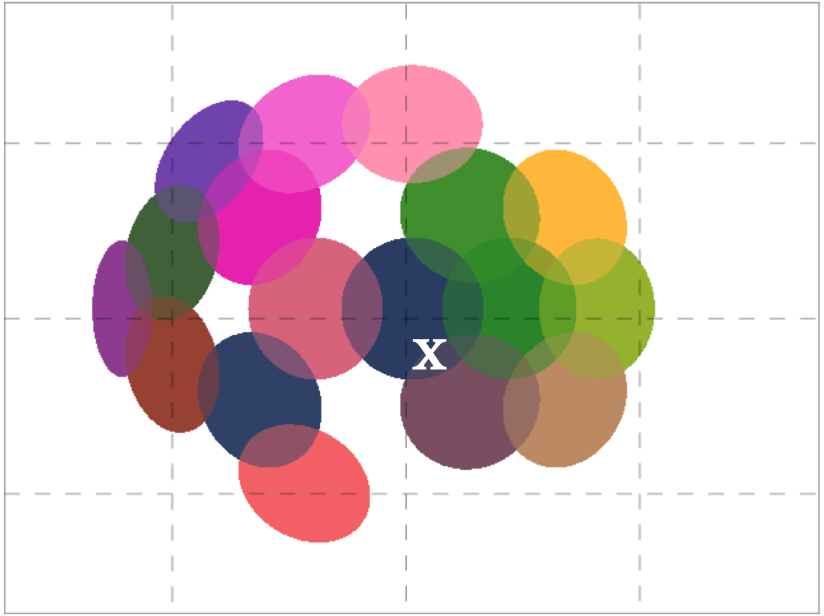


Inverse Rendering

Dr Cengiz Öztireli



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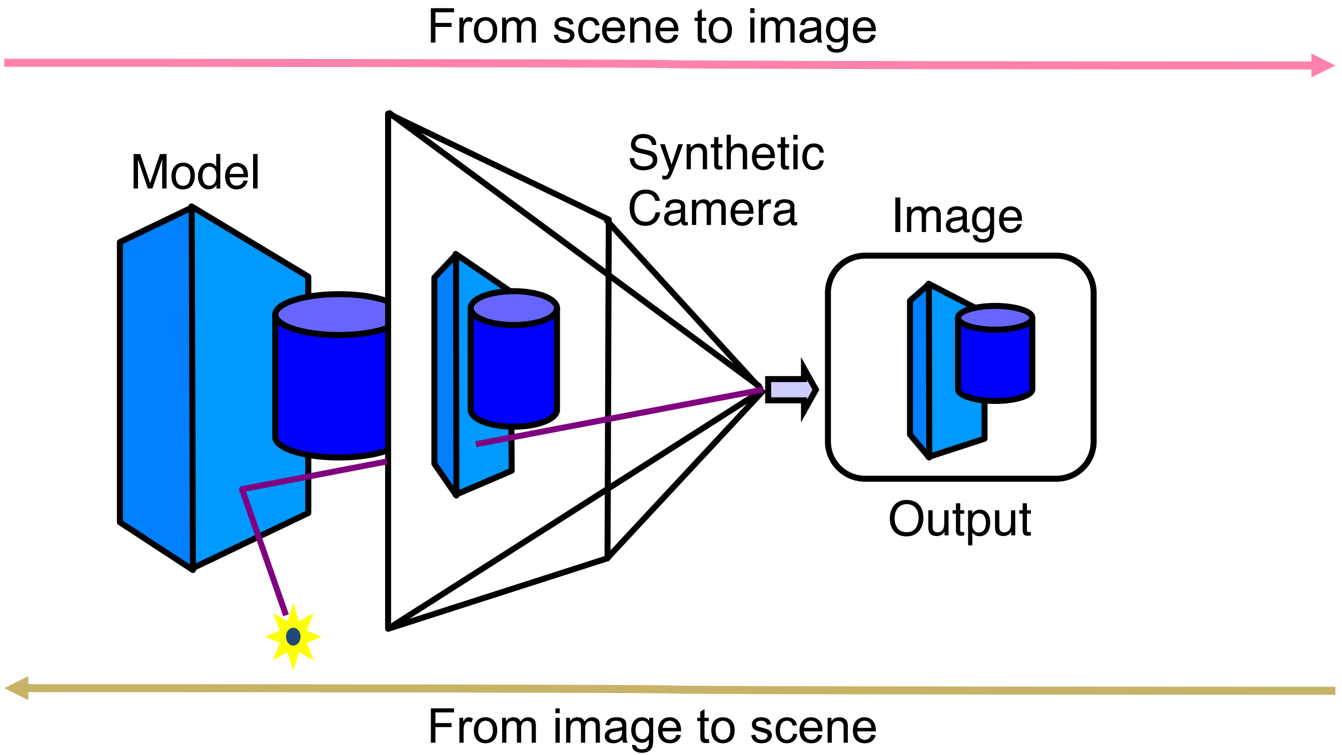
Forward / inverse rendering

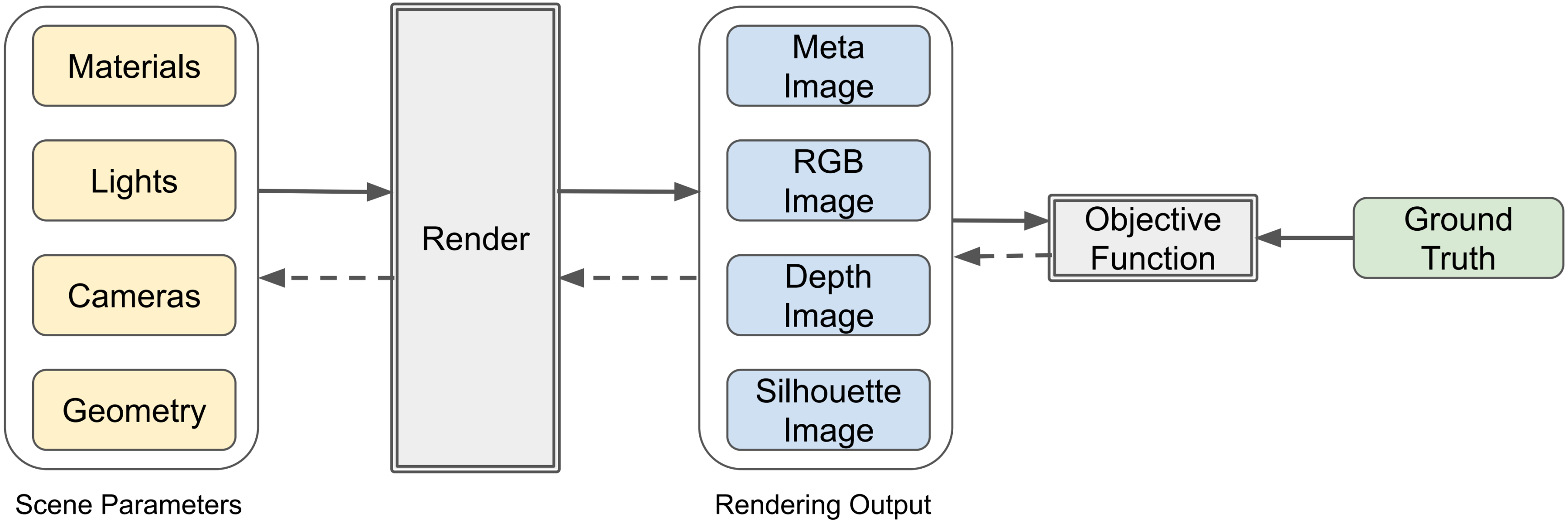


Forward / inverse rendering

Models for

Geometry
Motion
Appearance
Lighting
Camera
…

Forward / inverse rendering



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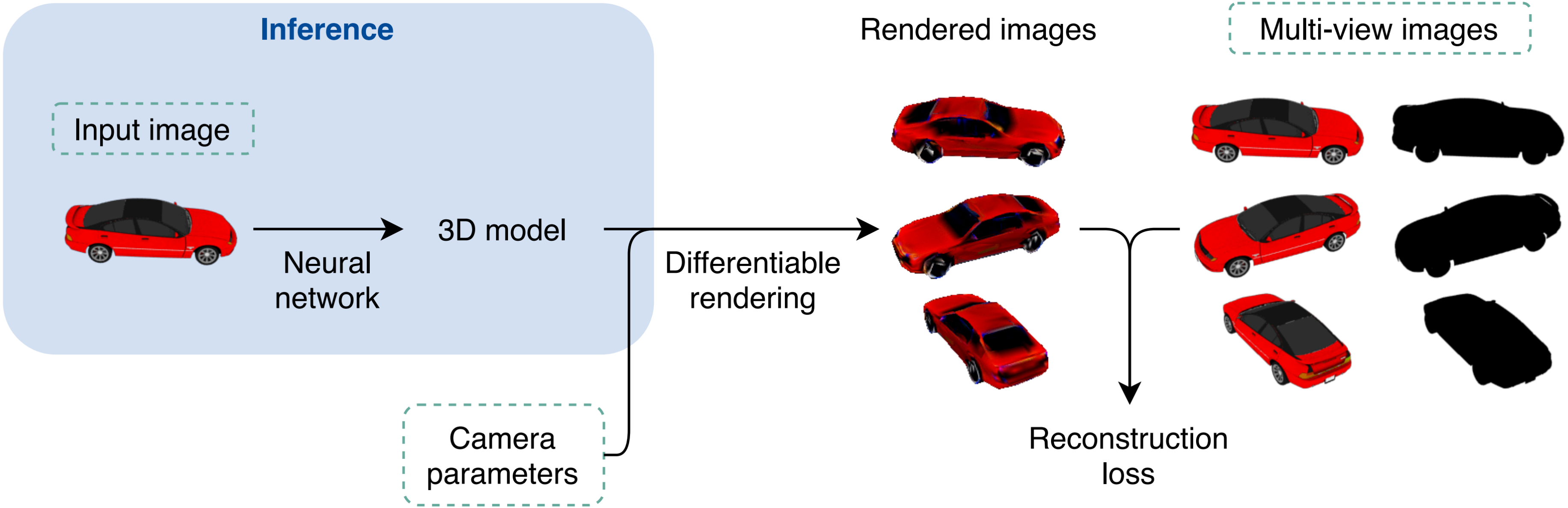
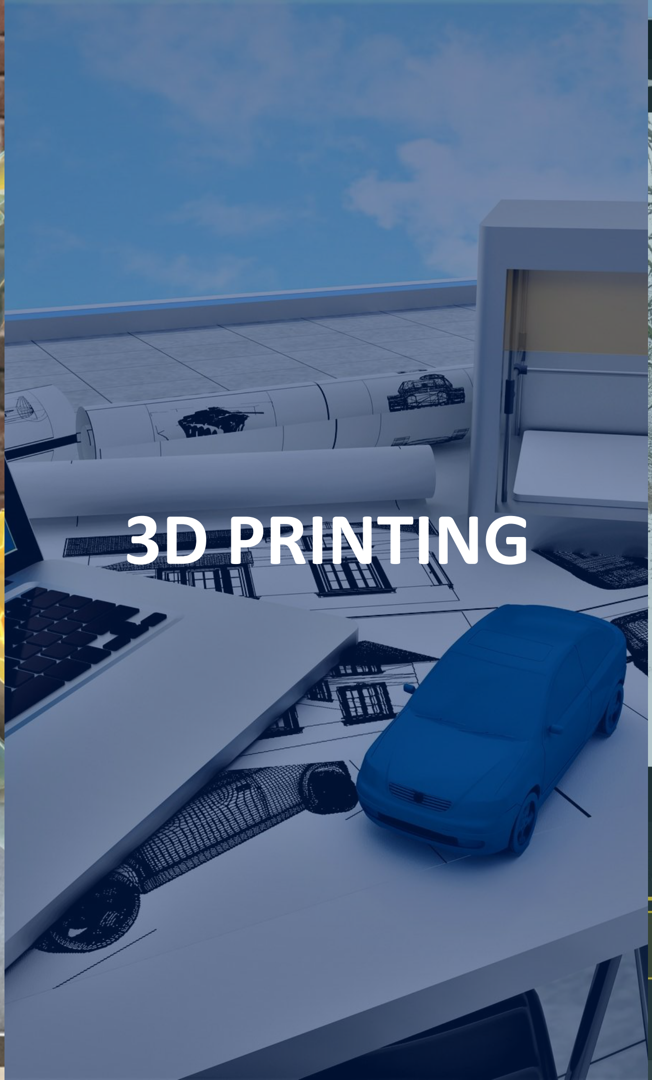
Forward / inverse rendering

Example: 3D geometry reconstruction




AR / VR

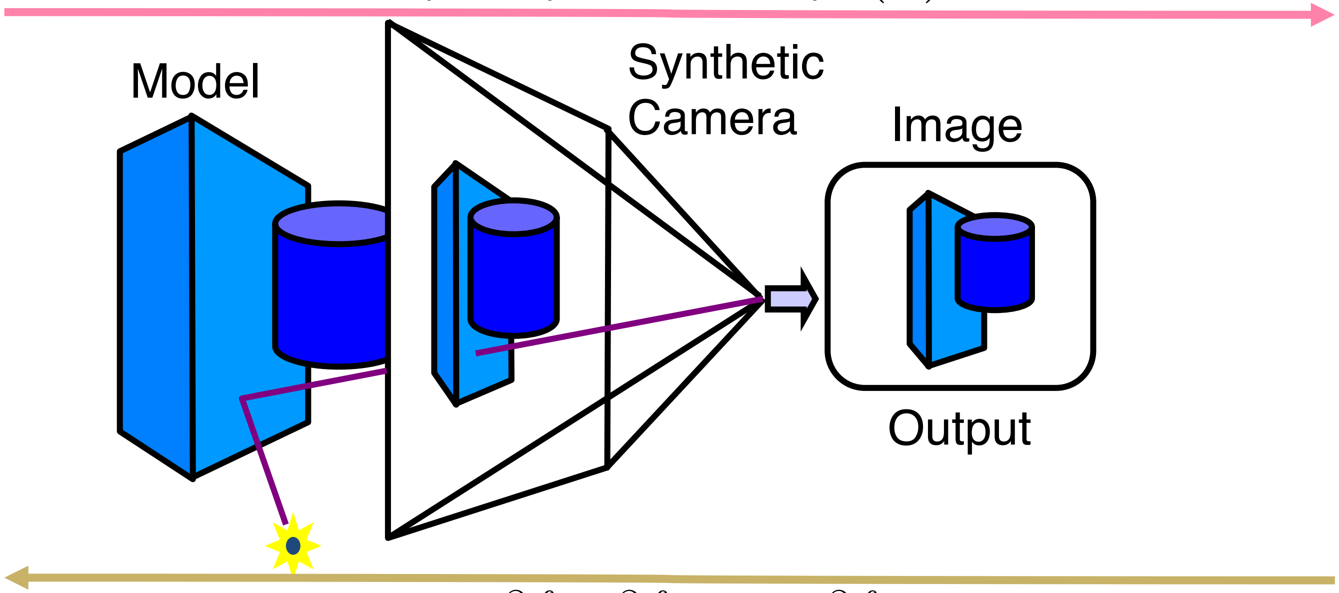

3D PRINTING


View
FreeCapture
2D EDITING
16:9
00:01:15
00:01:18
00:01:21
00:01:24
00:01:27

Inverse rendering

- Deep learning to help: make everything differentiable

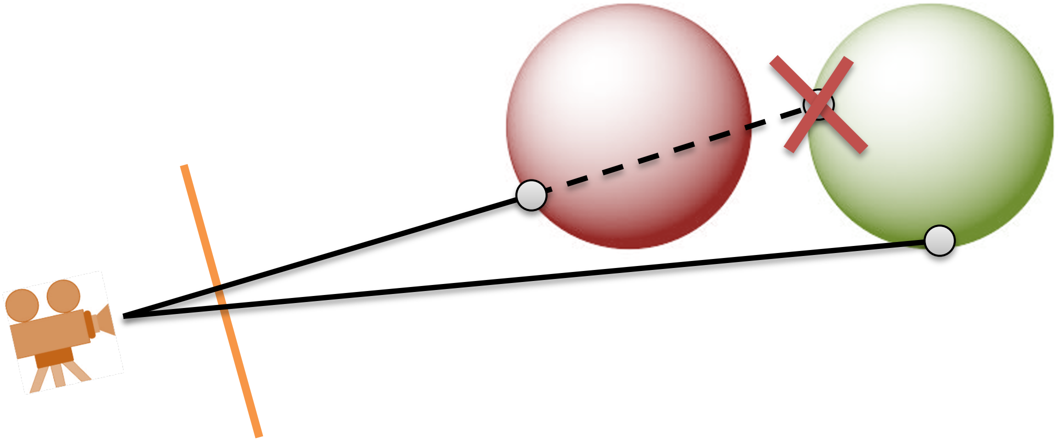
$$f_n \circ f_{n-1} \circ \cdots f_1(x)$$



$$\frac{\partial f_n}{\partial f_{n-1}} \frac{\partial f_{n-1}}{\partial f_{n-2}} \cdots \frac{\partial f_1}{\partial x}$$

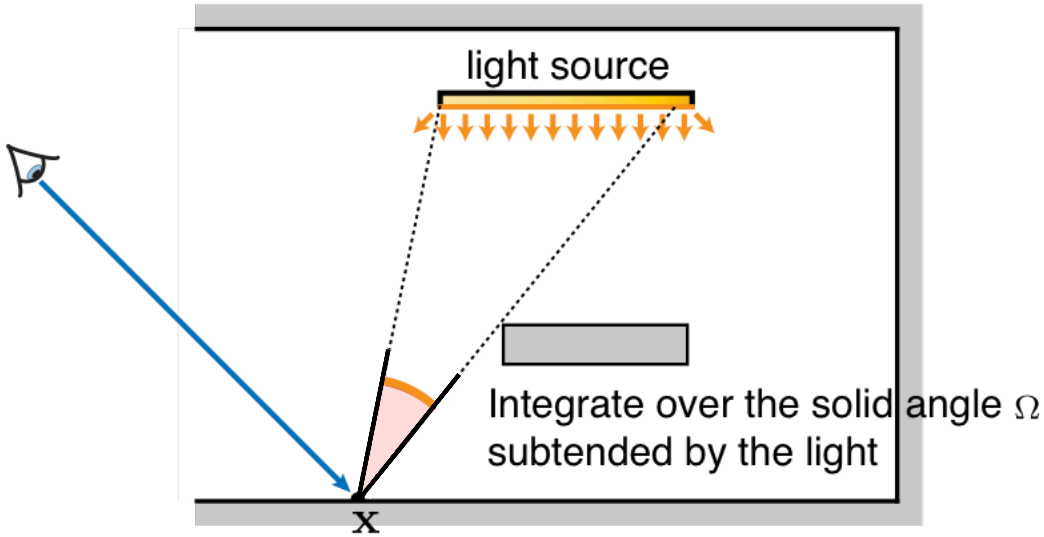
Inverse rendering

- Problem: Visibility is not differentiable



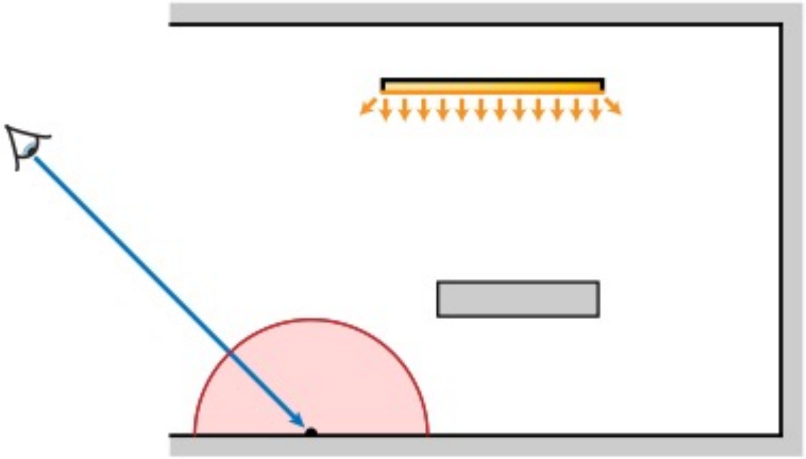
Surface Area Form

$$L_r(\mathbf{x}, \vec{\omega}_r) = \int_{\Omega} f_r(\mathbf{x}, \vec{\omega}_i, \vec{\omega}_r) L_e(\mathbf{r}(\mathbf{x}, \vec{\omega}_i), -\vec{\omega}_i) |\cos\theta_i| d\vec{\omega}_i$$



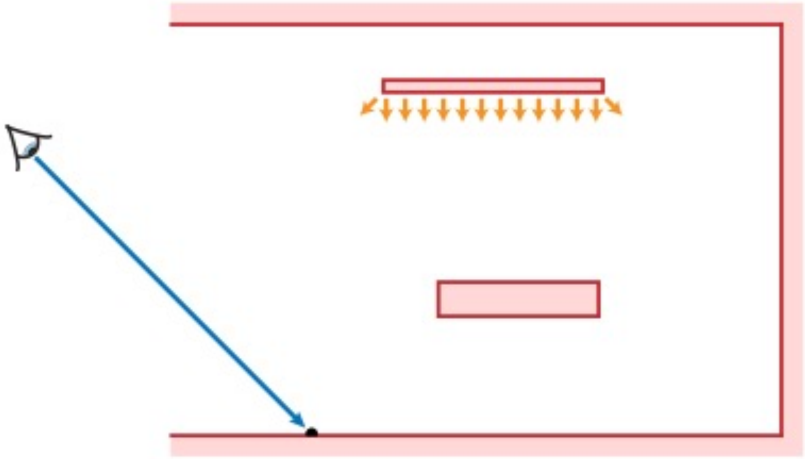
Surface Area Form

Hemispherical integration



$$L_r(\mathbf{x}, \vec{\omega}_r) = \int_{H^2} f_r(\mathbf{x}, \vec{\omega}_i, \vec{\omega}_r) L_i(\mathbf{x}, \vec{\omega}_i) \cos\theta_i \, d\vec{\omega}_i$$

Surface area integration

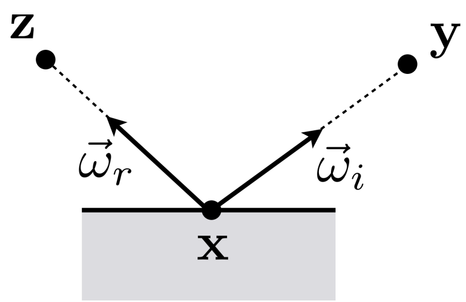


$$L_r(\mathbf{x}, \mathbf{z}) = \int_A f_r(\mathbf{x}, \mathbf{y}, \mathbf{z}) L_i(\mathbf{x}, \mathbf{y}) G(\mathbf{x}, \mathbf{y}) \, dA(\mathbf{y})$$

Surface Area Form

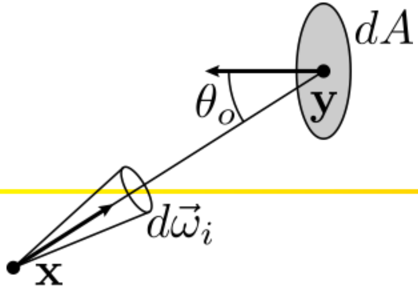
- Change in notation

$$L_i(\mathbf{x}, \vec{\omega}_i) = L_i(\mathbf{x}, \mathbf{y})$$
$$L_r(\mathbf{x}, \vec{\omega}_r) = L_r(\mathbf{x}, \mathbf{z})$$
$$f_r(\mathbf{x}, \vec{\omega}_i, \vec{\omega}_r) = f_r(\mathbf{x}, \mathbf{y}, \mathbf{z})$$



- Transform integral over directions to over surface area

Jacobian of the transform: $$d\vec{\omega}_i = \frac{|\cos\theta_o|}{\|\mathbf{x}-\mathbf{y}\|^2} dA$$



Surface Area Form

- Surface area form

$$L_r(\mathbf{x}, \mathbf{z}) = \int_A f_r(\mathbf{x}, \mathbf{y}, \mathbf{z}) L_i(\mathbf{x}, \mathbf{y}) G(\mathbf{x}, \mathbf{y}) \, dA(\mathbf{y})$$

Geometry term

$$G(\mathbf{x}, \mathbf{y}) = V(\mathbf{x}, \mathbf{y}) \frac{|\cos\theta_i| |\cos\theta_o|}{||\mathbf{x} - \mathbf{y}||^2}$$

Visibility term

Original foreshortening term

Jacobian determinant of the transform

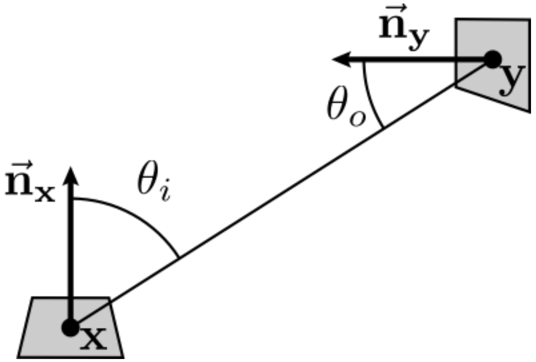
Surface Area Form

- Interpreting the new cosine term

$$G(\mathbf{x},\mathbf{y}) = V(\mathbf{x},\mathbf{y}) \frac{|\cos\theta_i|\,|\cos\theta_o|}{\|\mathbf{x}-\mathbf{y}\|^2}$$

• The chance that a photon emitted from a differential patch will hit another differential patch decreases as:

  - the patches **face away** from each other (numerator)
  - the patches **move away** from each other (denominator)



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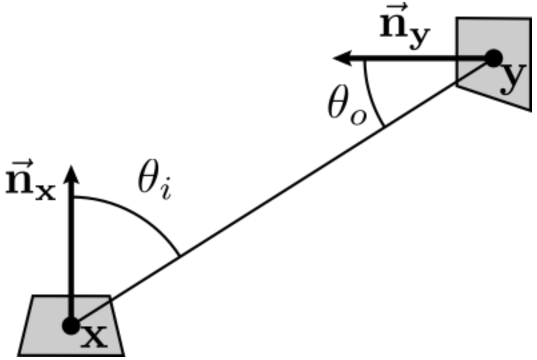
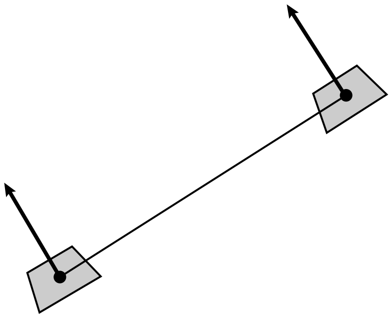
Surface Area Form

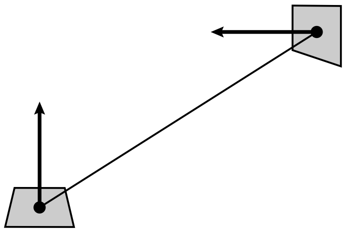
- Interpreting the new cosine term



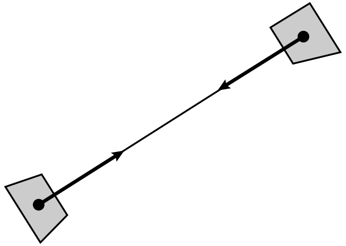
$$G(\mathbf{x}, \mathbf{y}) = V(\mathbf{x}, \mathbf{y}) \; \frac{|\cos\theta_i| \, |\cos\theta_o|}{\|\mathbf{x} - \mathbf{y}\|^2}$$



numerator = 0



0 < numerator < 1



numerator = 1

Visibility Term

- Surface area form

$$L_r(\mathbf{x},\mathbf{z}) = \int_A f_r(\mathbf{x},\mathbf{y},\mathbf{z}) L_i(\mathbf{x},\mathbf{y}) \boxed{G(\mathbf{x},\mathbf{y})}\, dA(\mathbf{y})$$

Geometry term

$$G(\mathbf{x},\mathbf{y}) = \boxed{V(\mathbf{x},\mathbf{y})} \frac{|\cos\theta_i|\,|\cos\theta_o|}{\|\mathbf{x}-\mathbf{y}\|^2}$$

Visibility term

$$V(\mathbf{x},\mathbf{y}) = \begin{cases} 1: & \text{visible} \\ 0: & \text{not visible} \end{cases}$$

Discontinuous!

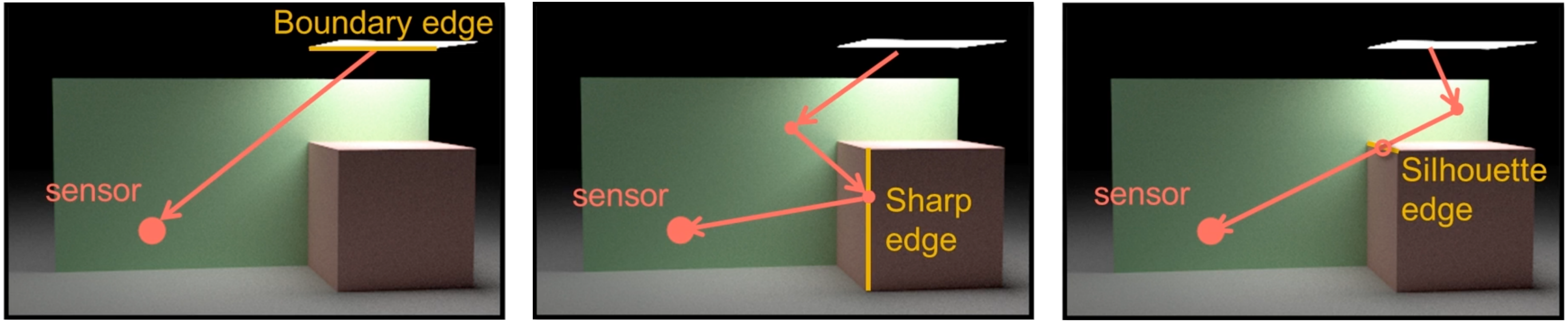
Visibility Term

- Problem with discontinuities and differentiability

$$\frac{\partial}{\partial \pi} \int_A f(\mathbf{x}) d\mathbf{x} \neq \int_A \frac{\partial}{\partial \pi} f(\mathbf{x}) d\mathbf{x}$$

Visibility Term

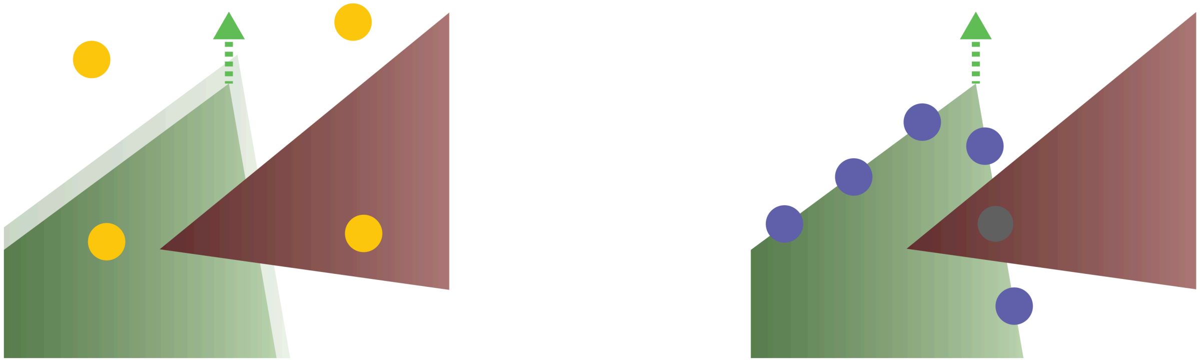
- Sources of discontinuities due to visibility



Zhang et al., Path-Space Differentiable Rendering, 2020.

Differentiable Visibility

- Edge-sampling for accurate gradients



Standard sampling — Edge sampling

Li et al., Differentiable Monte Carlo Ray Tracing through Edge Sampling, 2018.

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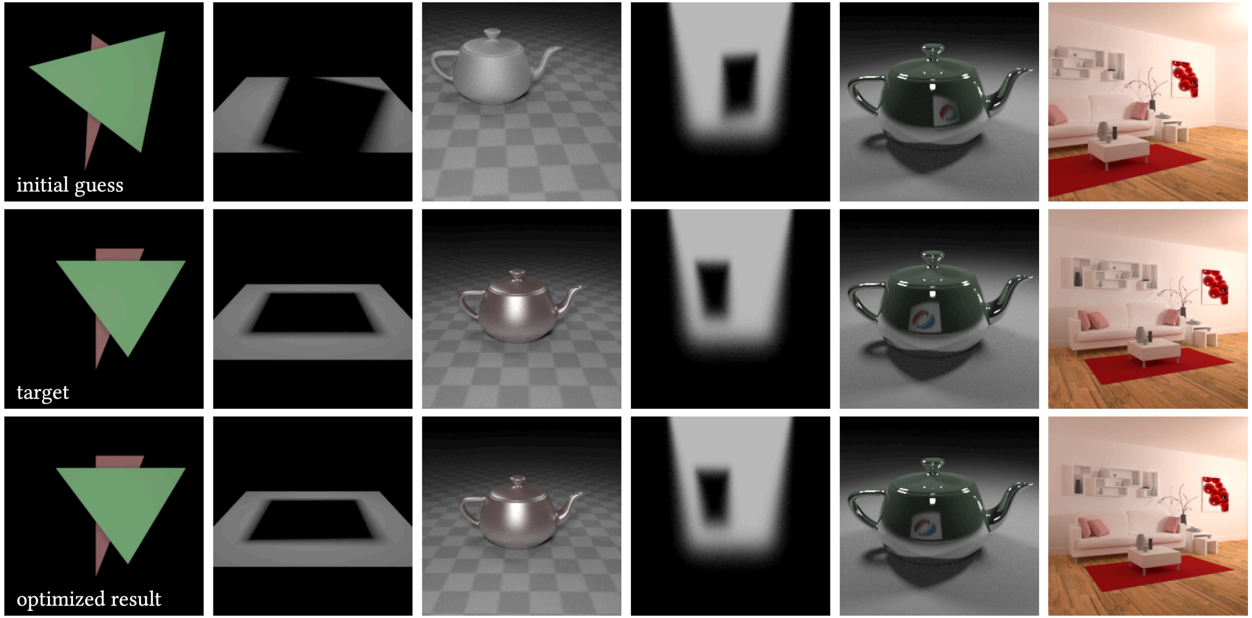
Differentiable Visibility

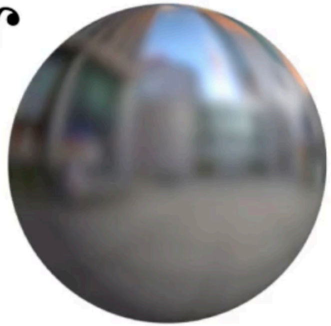
- Edge-sampling for accurate gradients



Li et al., Differentiable Monte Carlo Ray Tracing through Edge Sampling, 2018.

Differentiable Visibility

- Re-parametrizing discontinuities

$\int$  $d\omega$ $=$ $\int$  $d\omega$

integrand

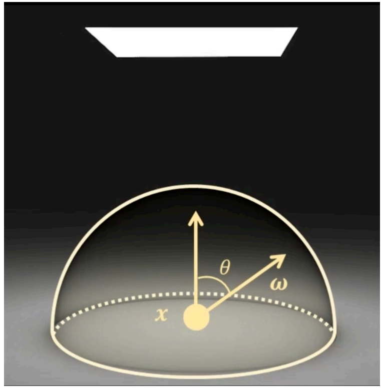
convolved integrand

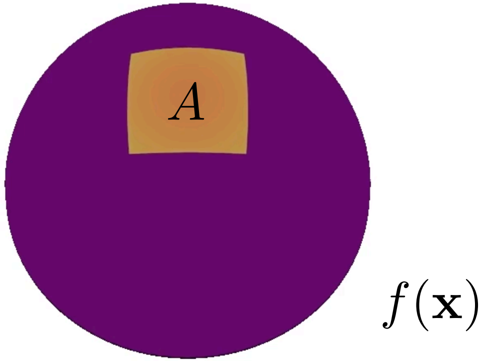
Loubet et al., Reparameterizing discontinuous integrands for differentiable rendering, 2019.

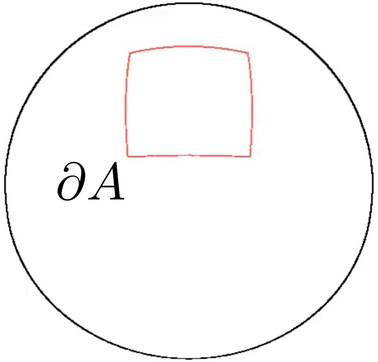
Differentiable Visibility

- Reynolds transport theorem

$$\frac{\partial}{\partial \pi} \int_A f(\mathbf{x}) d\mathbf{x} = \int_A \frac{\partial}{\partial \pi} f(\mathbf{x}) d\mathbf{x} + \int_{\partial A} g(\mathbf{l}) d\mathbf{l}$$







Zhang et al., Path-Space Differentiable Rendering, 2020.

Frameworks

- Automatic differentiation
- Fast & parallel computation
- Active development

TensorFlow Graphics

PyTorch3D