SIGGRAPH 2023
LOS ANGELES+ 6-10 AUG

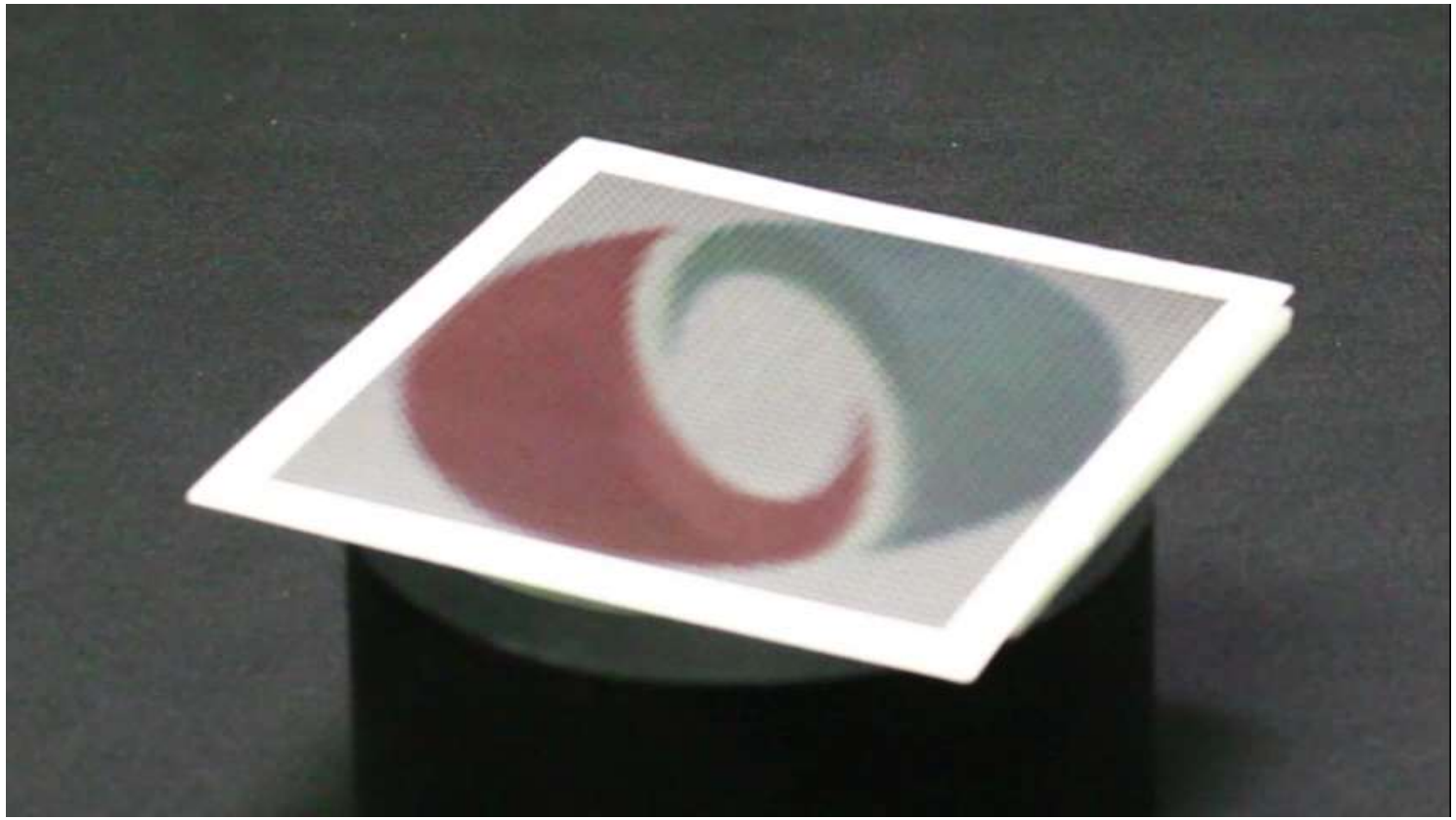
THE PREMIER CONFERENCE & EXHIBITION ON
COMPUTER GRAPHICS & INTERACTIVE TECHNIQUES

Scratch-based Reflection Art via Differentiable Rendering

Pengfei Shen[1], Ruizeng Li[1], Beibei Wang[2, 3], and Ligang Liu[1]

[1]Universty of Science and Technology of China
[2]Nankai University
[3]Nanjing University of Science and Technology

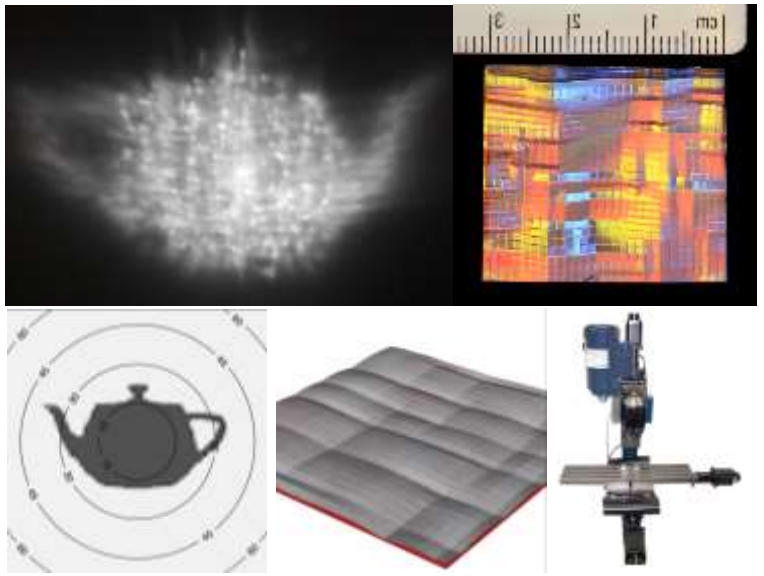
3D REFLECTION ARTS



[Sakurai et al. 2018]

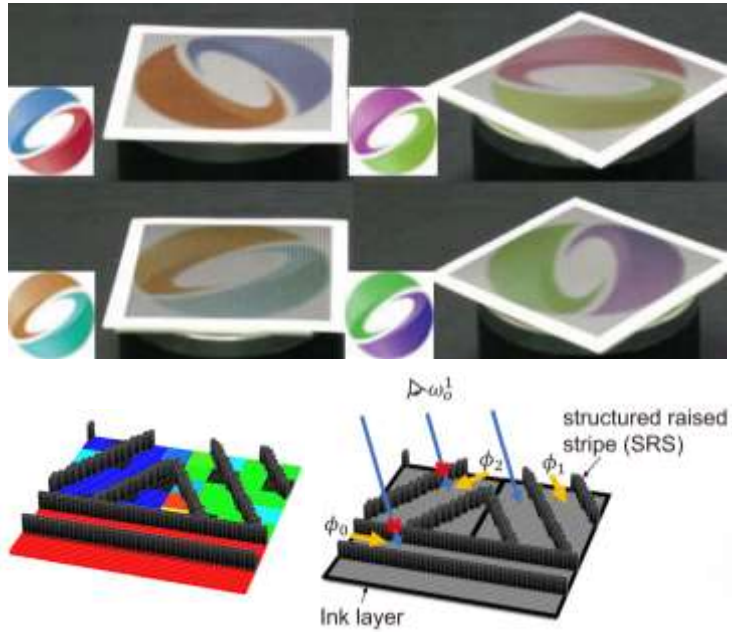
PREVIOUS WORK

- Low resolution (30x30 facets)
- Single pattern



[Weyrich et al. 2009]

- Computation time (a few hours)



[Sakurai et al. 2018]

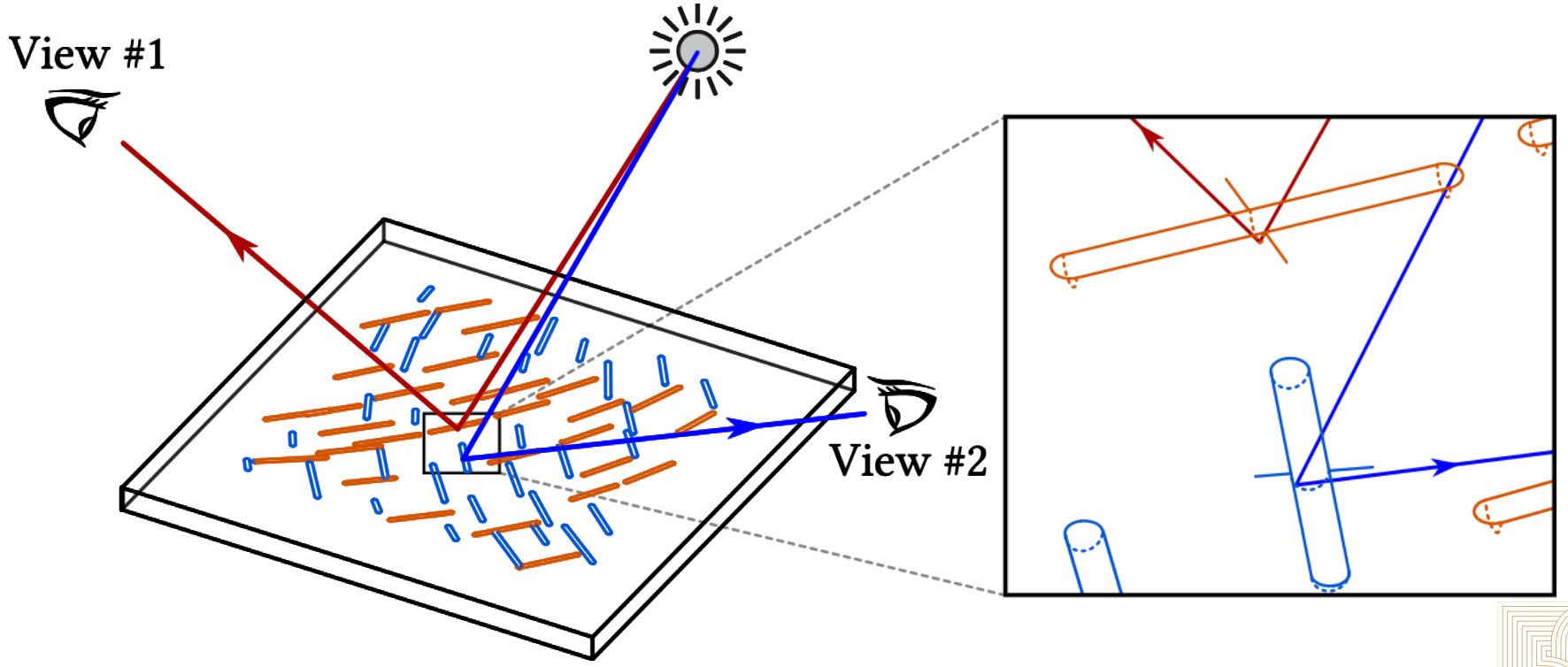
SCRATCH-BASED REFLECTION ART

Scratches:

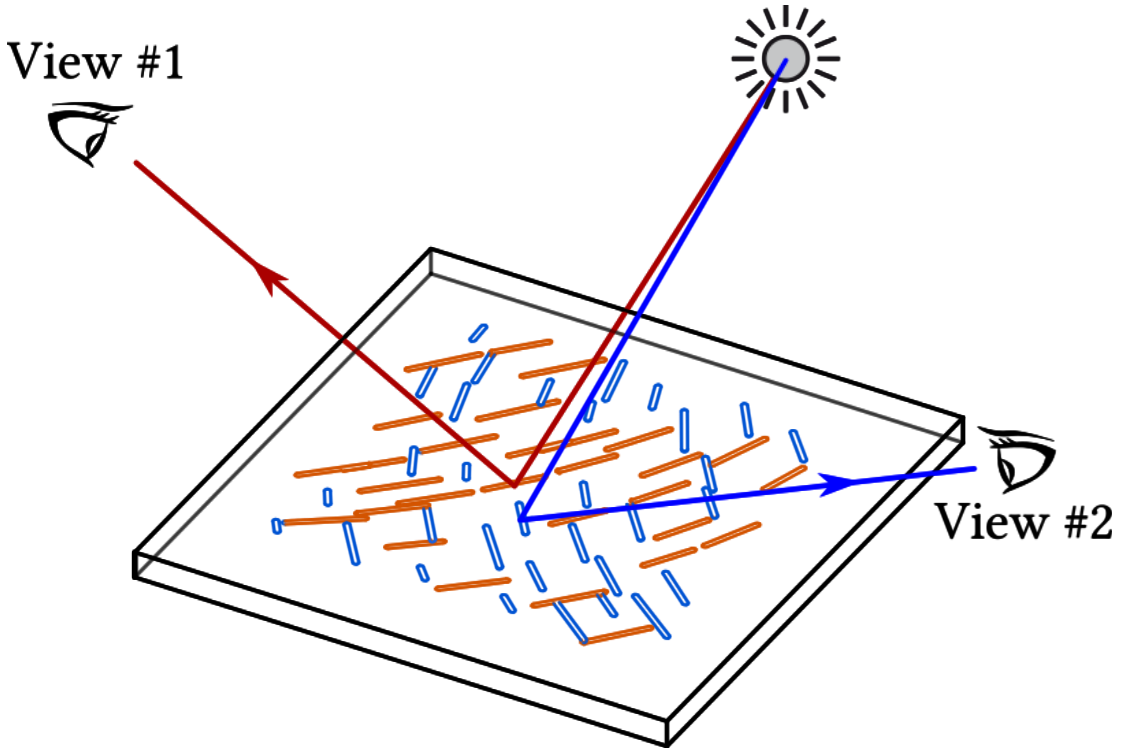
- Easy to fabricate
- No limitation from resolution

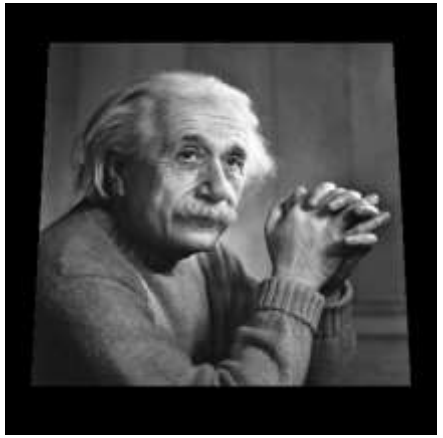
SCRATCH-BASED REFLECTION ART

- Special optical properties



PROBLEM STATEMENT





FORMULATION

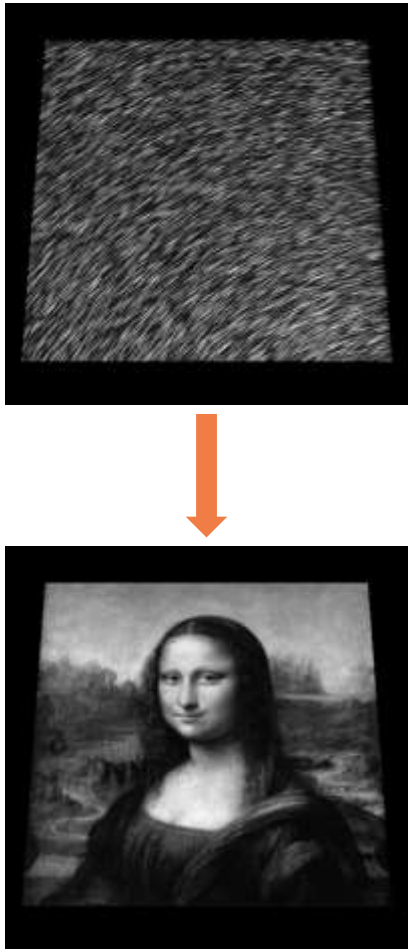
Scratches' parameters

View Light

$$\min_{\mathcal{S}} E_{\text{loss}}\left(\{I_j(\mathcal{S}; V_j, L_j), T_j\}_j\right)$$

Rendered result

Target

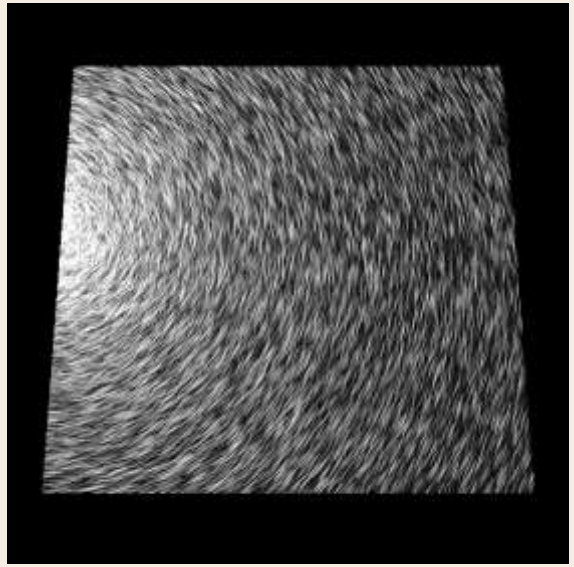


Main challenges:

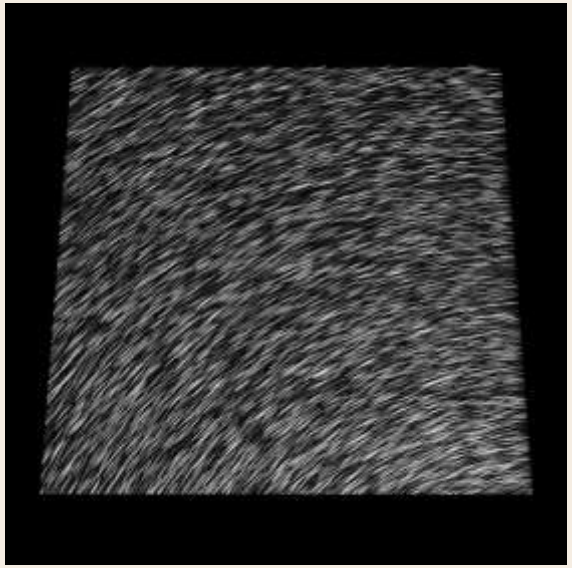
Efficient rendering and optimization of scratches

OUR SOLUTION

Analytical scratch models

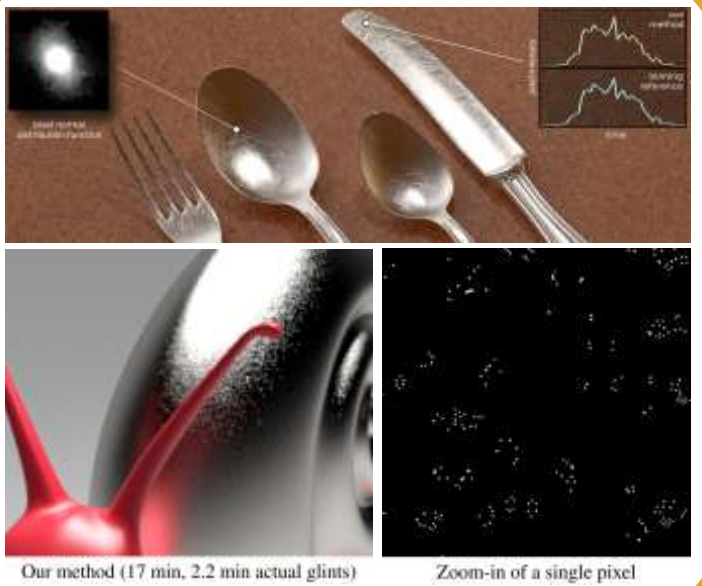


Inverse rendering pipeline

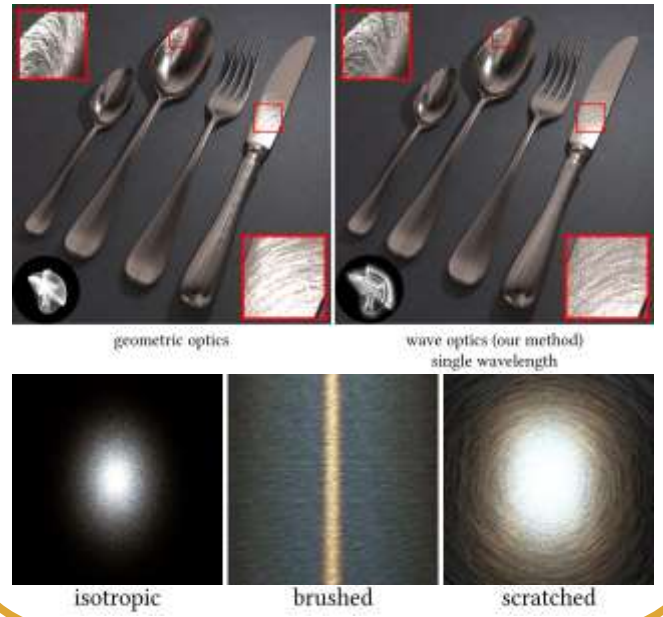


Real objects fabrication

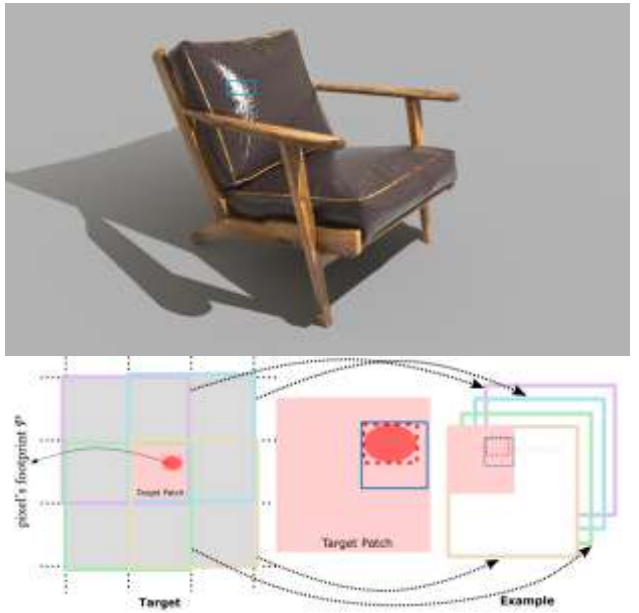
GLINTS RENDERING



[Yan et al. 2014]



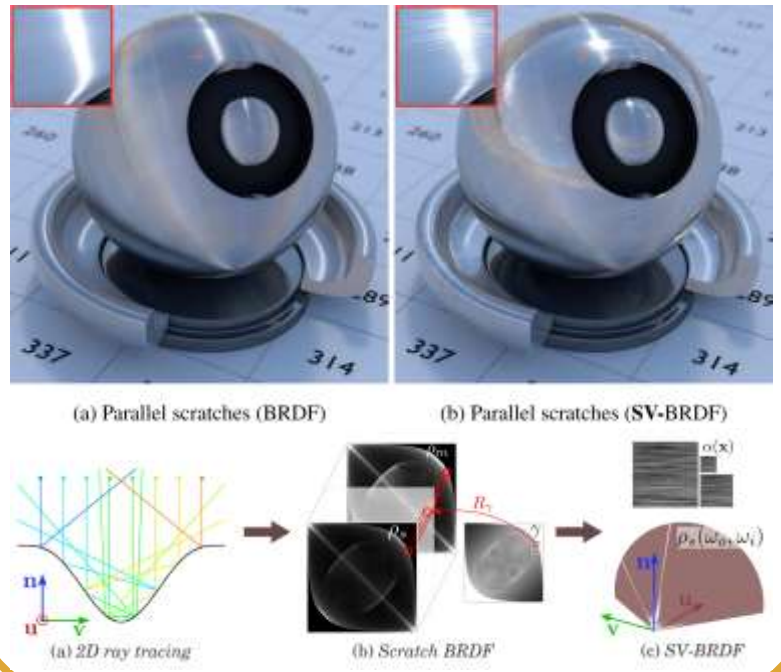
[Yan et al. 2018]



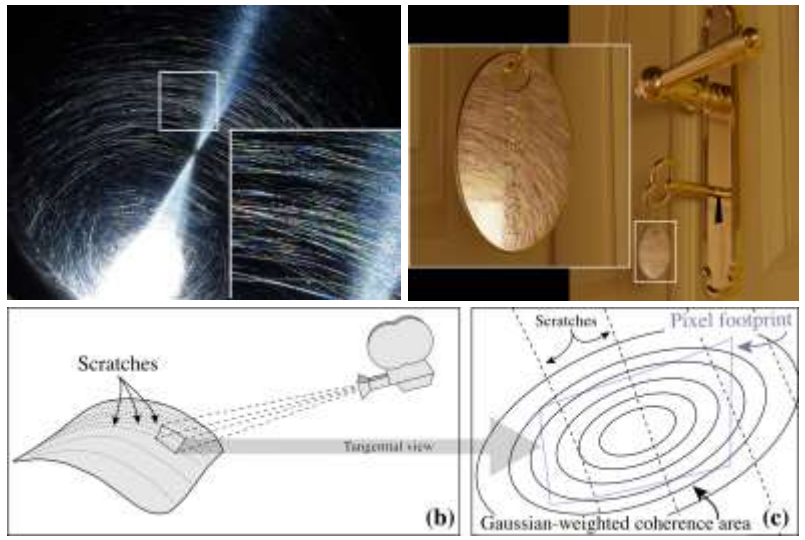
[Wang et al. 2020]

- High-resolution normal maps are challenging for optimization

PREVIOUS WORK



[Raymond et al. 2016]

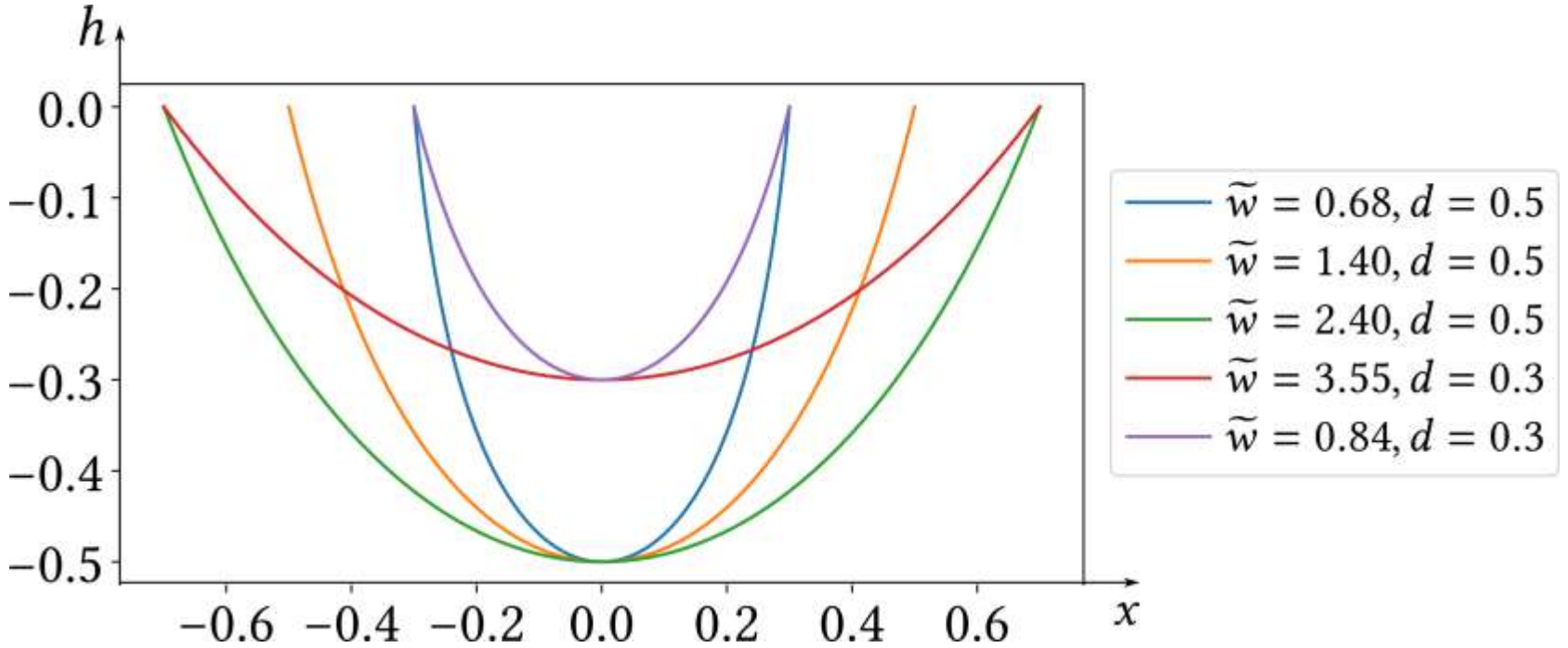


[Werner et al. 2017]

DESIRED FEATURE OF THE SCRATCH MODEL

- Individual scratch representation
- Efficient for forward rendering
- Easy to perform differentiable rendering

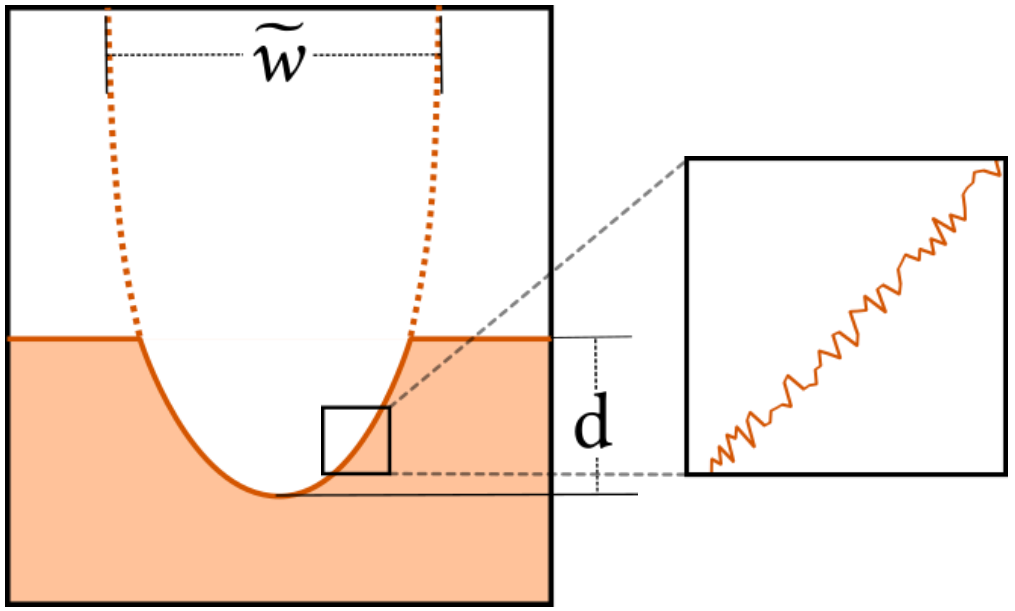
SCRATCH GEOMETRIC MODEL



$$h(x; \tilde{w}, d) = -\frac{1}{2}\tilde{w} \log\left(1 - \frac{4x^2}{\tilde{w}^2}\right) - d$$

SCRATCH SHADING MODEL

$$\mathbf{n}(x;\widetilde{w}) = \frac{(-h_x(x;\widetilde{w},d),0,1)}{\|(-h_x(x;\widetilde{w},d),0,1)\|}$$
$$= \left(-\frac{4\widetilde{w}x}{\widetilde{w}^2+4x^2}, 0, \frac{\widetilde{w}^2-4x^2}{\widetilde{w}^2+4x^2}\right)$$



Point NDF

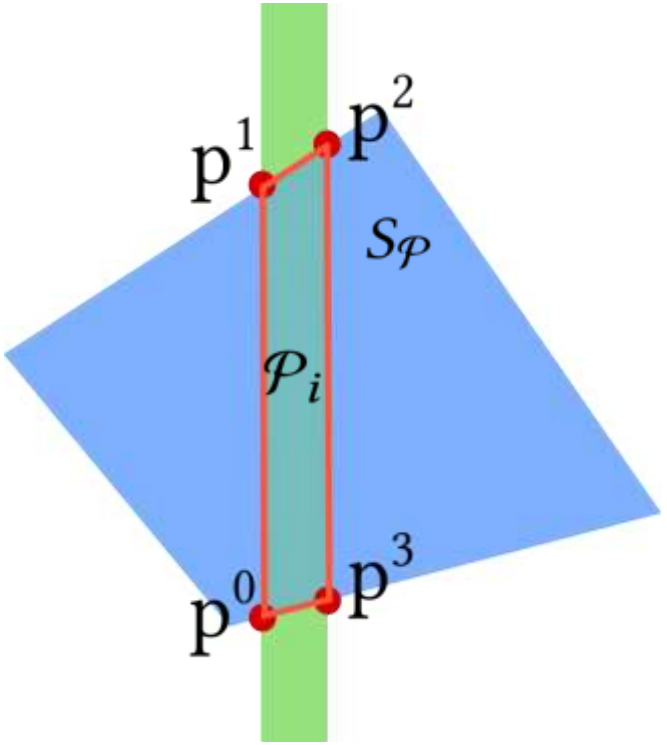
$$D_x(\mathbf{h},\mathbf{n}(x)) = \frac{\alpha^2\chi^+(\mathbf{n}(x)\cdot\mathbf{h})}{\pi\left((\mathbf{n}(x)\cdot\mathbf{h})^2\left(\alpha^2-1\right)+1\right)^2}$$

SCRATCH SHADING MODEL

Patch NDF (Single scratch)

$$D_i(\mathbf{h}) = \frac{1}{S_{\mathcal{P}}} \int_{\mathcal{P}_i} D_x(\mathbf{h}, \mathbf{n}(x))\, \mathrm{d}x\mathrm{d}y$$

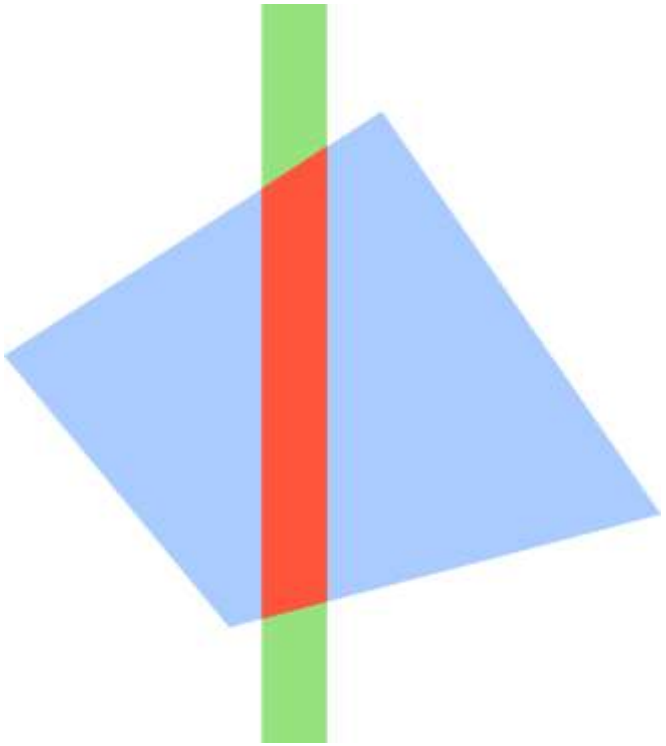
$$\hat{D}_i(\mathbf{h}) = \sum_{k=1}^{k=K} \int_{p_x^k}^{p_x^{k+1}} S(x) D_x(\mathbf{h}, \mathbf{n}(x))\mathrm{d}x$$



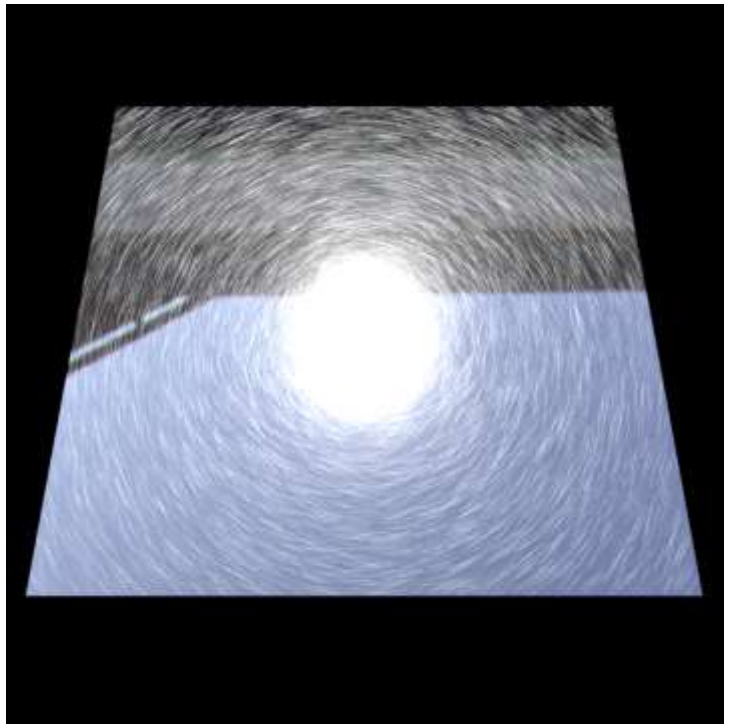
SCRATCH SHADING MODEL

$$D_{\mathcal{P}}(\mathbf{h}) = \sum_{i \in \mathcal{P}} D_i(\mathbf{h})$$

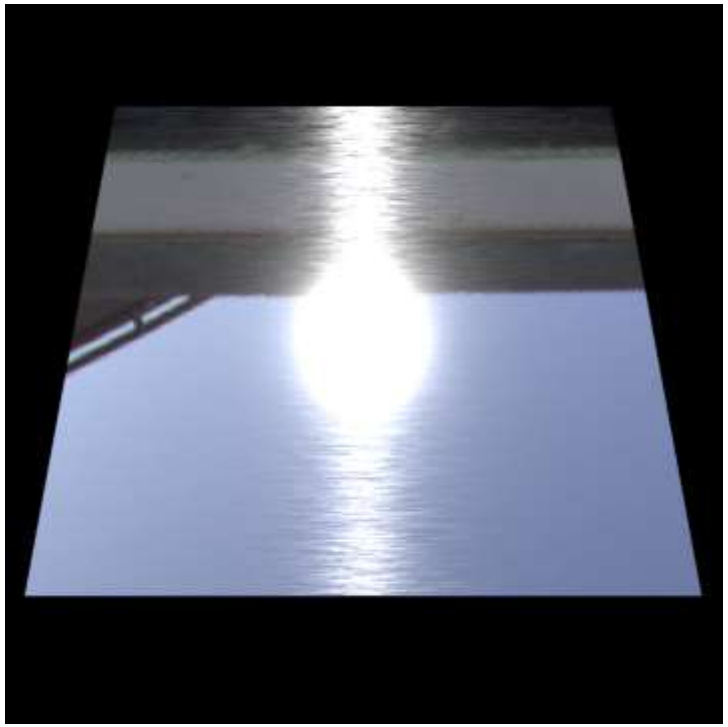
$$f_{\text{scratch}}(\omega_{\text{i}}, \omega_{\text{o}}) = \frac{D_{\mathcal{P}}(\mathbf{h}) G(\omega_{\text{i}}, \omega_{\text{o}}) F(\omega_{\text{o}}, \mathbf{h})}{4|\omega_{\text{i}} \cdot \mathbf{n}||\omega_{\text{o}} \cdot \mathbf{n}|}$$



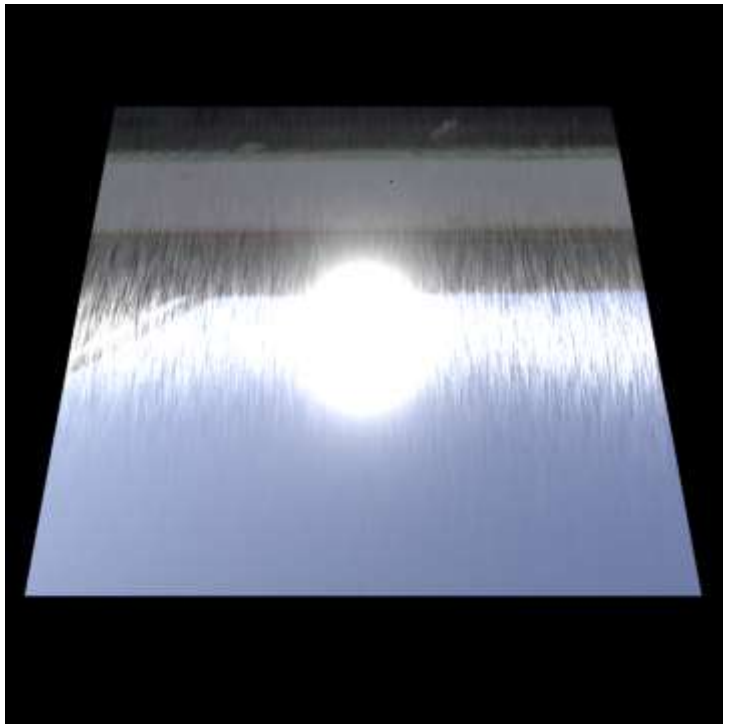
SCRATCH SHADING MODEL



Random



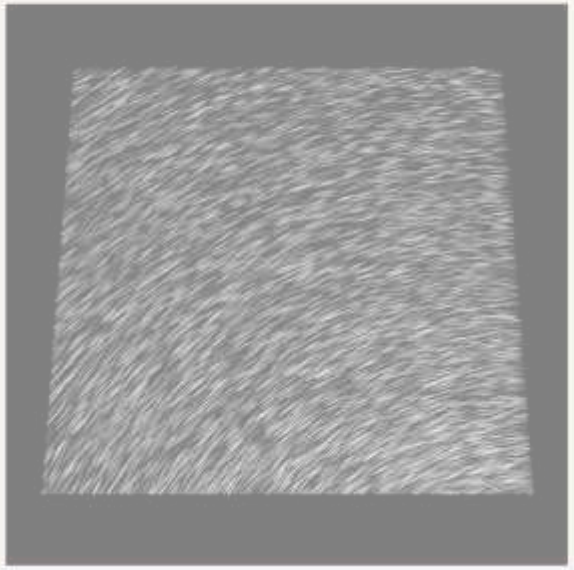
Horizontally-brushed



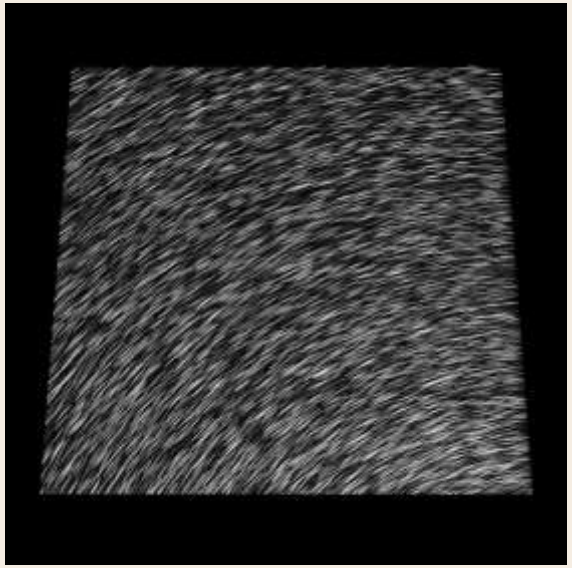
Vertically-brushed

OUR SOLUTION

Analytical scratch models



Inverse rendering pipeline



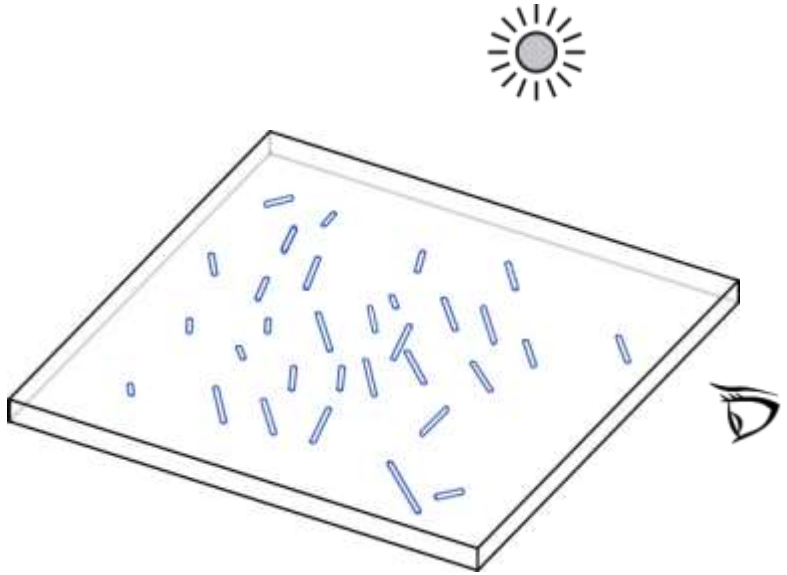
Real objects fabrication

INVERSE PARAMETER ESTIMATION

Fixed

$$\min_{\mathcal{S}} \; E_{\text{loss}} \left(\{ I_j(\mathcal{S}; V_j, L_j), T_j \}_j \right)$$

Scratch parameters



LOSS FUNCTION

$$E_{\text{loss}} = \lambda_p E_p + \lambda_g E_g$$

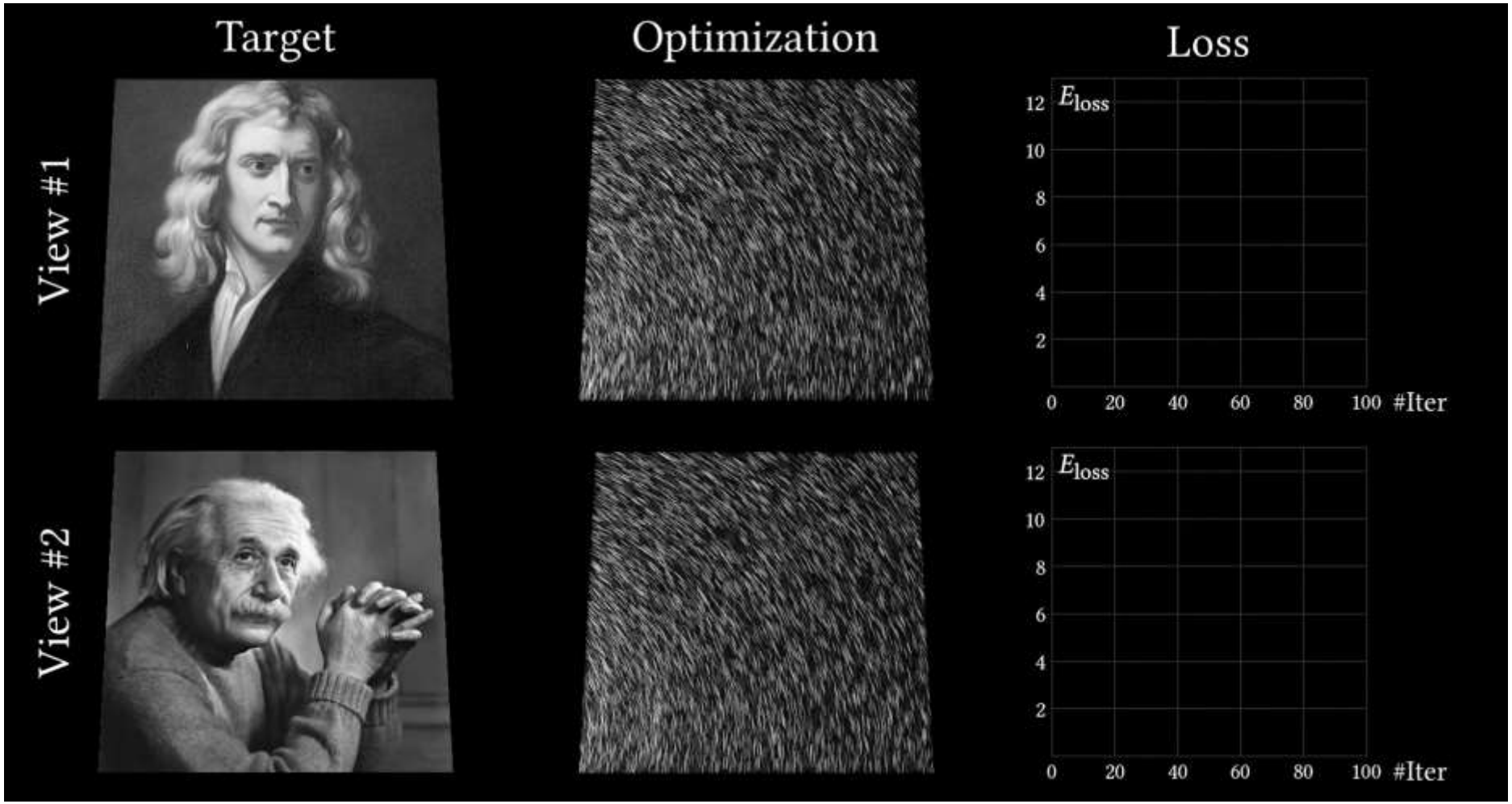
- Perceptual loss (Chizhov et al. [2022])

$$E_p = \sum_j ||g * (I_j - T_j)||_2^2$$

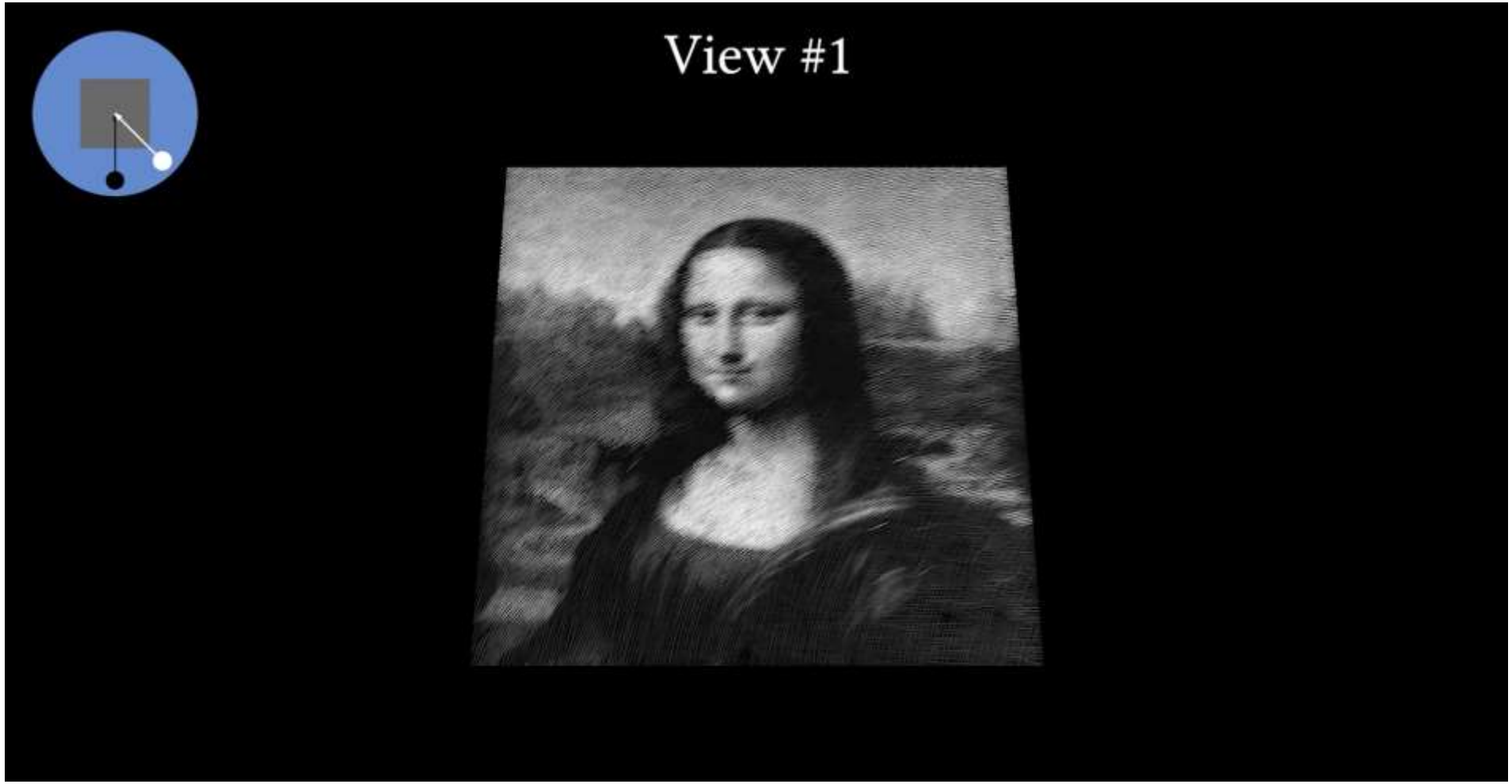
- Gram matrix loss (Gatys et al. [2015])

$$E_g = \sum_j ||\text{Gram}(I_j) - \text{Gram}(T_j)||_2^2$$

OPTIMIZATION

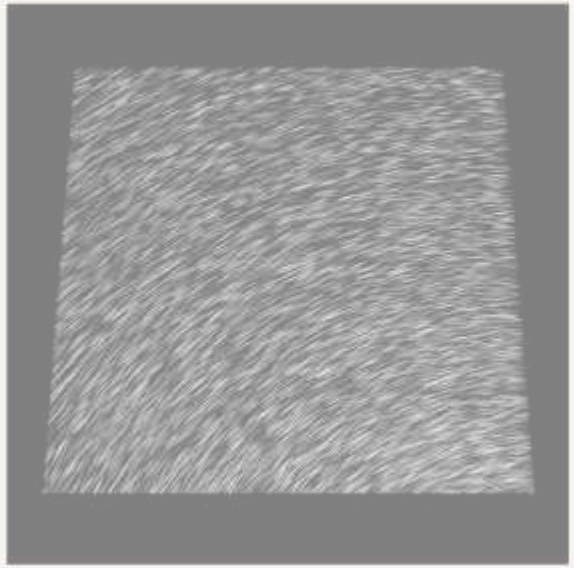


VIRTUAL RESULTS



OUR SOLUTION

Analytical scratch models



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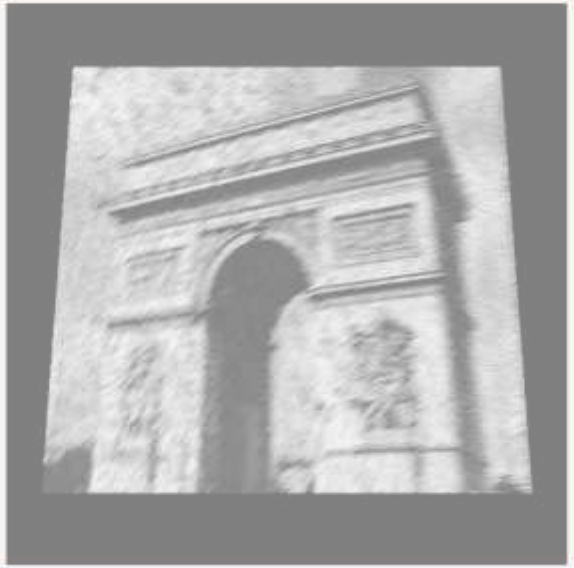
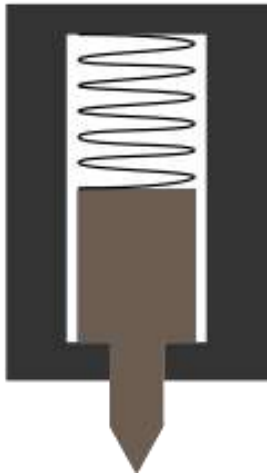
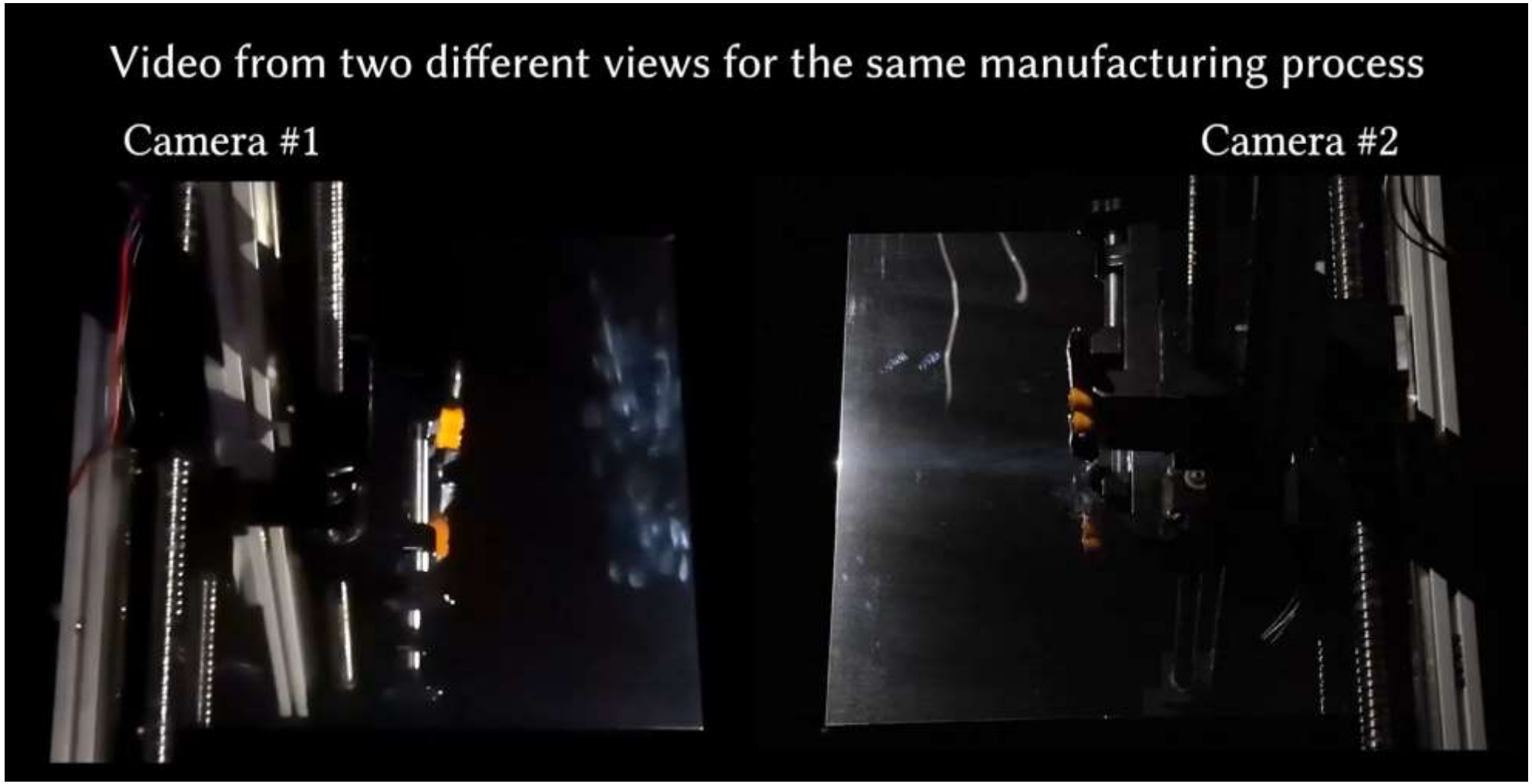


Real objects fabrication

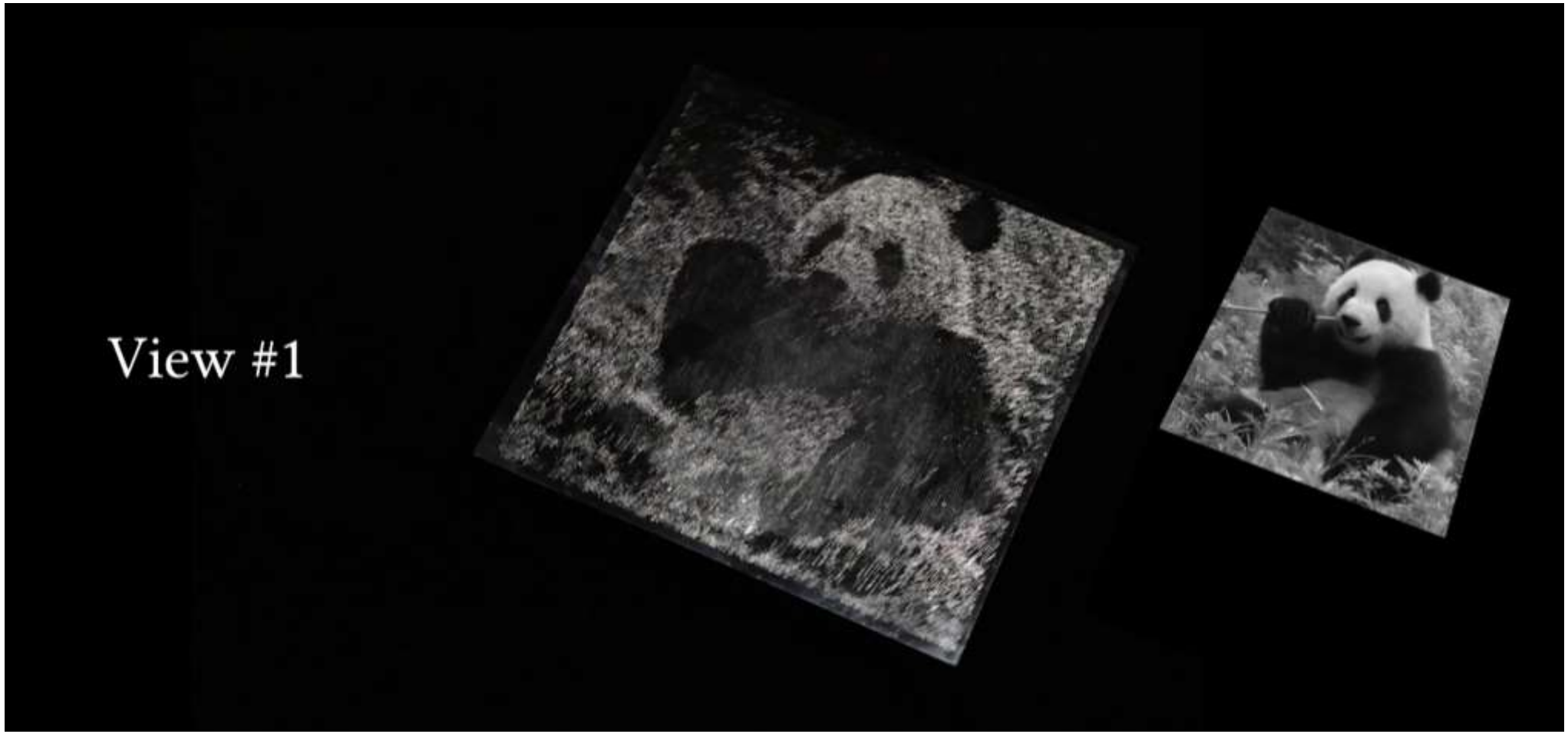
MANUFACTURE SETUP



MANUFACTURE



MANUFACTURED RESULTS

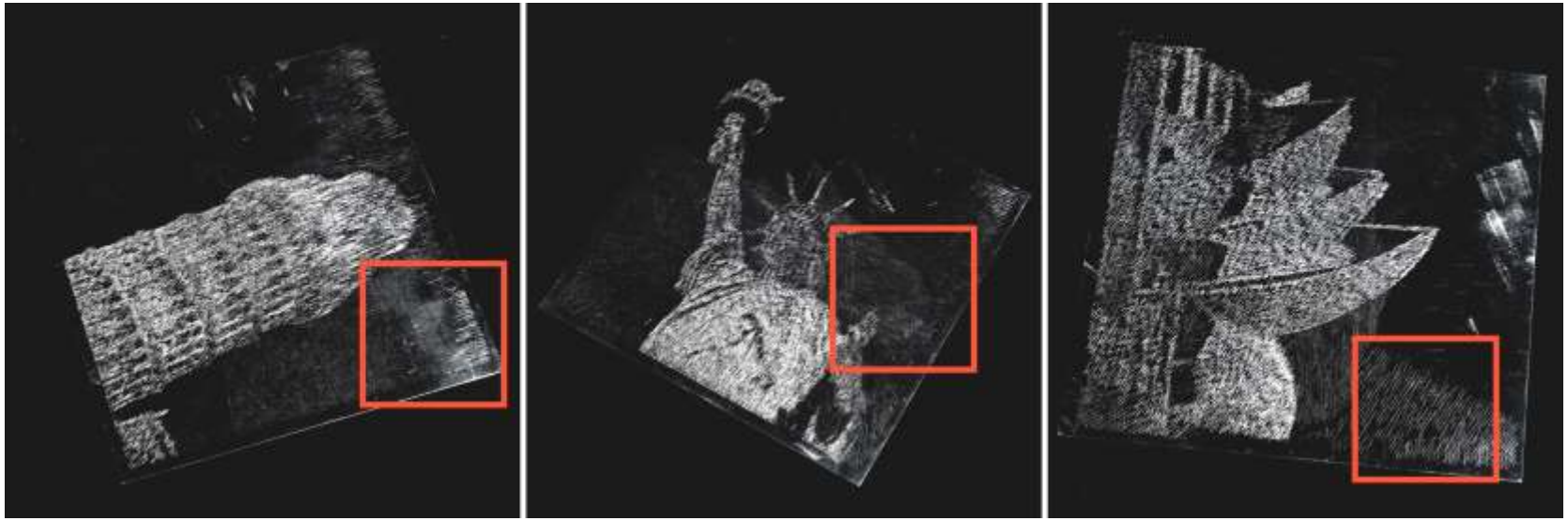


CONCLUSION

- Present scratch-based reflection art
- Introduce differentiable rendering for scratches
- Fabricate designed reflectors with a simple carving machine

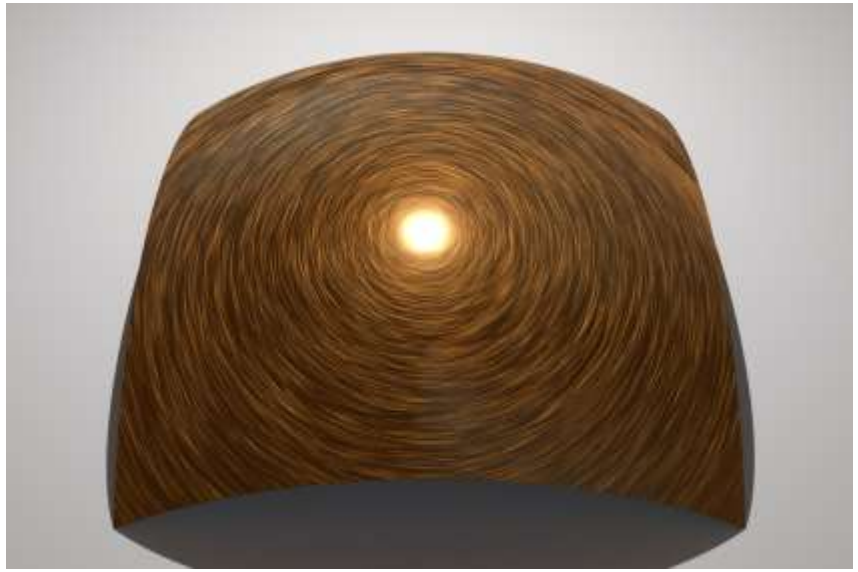
LIMITATIONS

- Expressiveness of our geometric and shading models
- Conflicts among different views



FUTURE WORK

- Design scratched-based reflection art on non-planar objects
- More applications like hair reconstruction



[Kuang et al. 2022]

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THANK YOU!

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