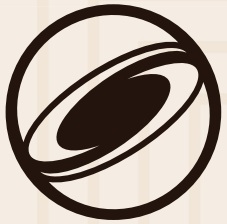

SIGGRAPH 2023
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THE PREMIER CONFERENCE & EXHIBITION ON
COMPUTER GRAPHICS & INTERACTIVE TECHNIQUES

DIFFERENTIABLE HEIGHTFIELD PATH TRACING WITH ACCELERATED DISCONTINUITIES

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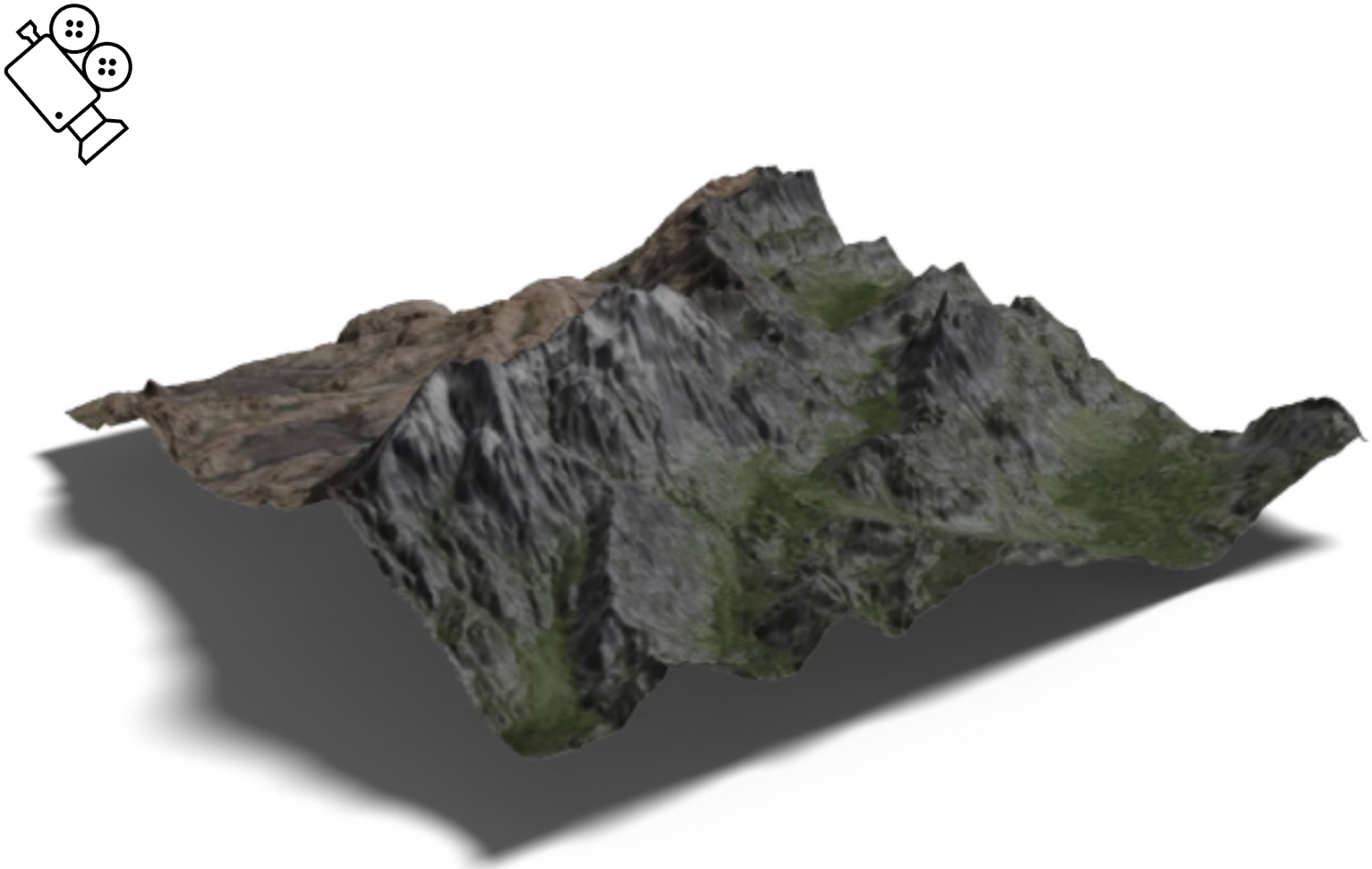
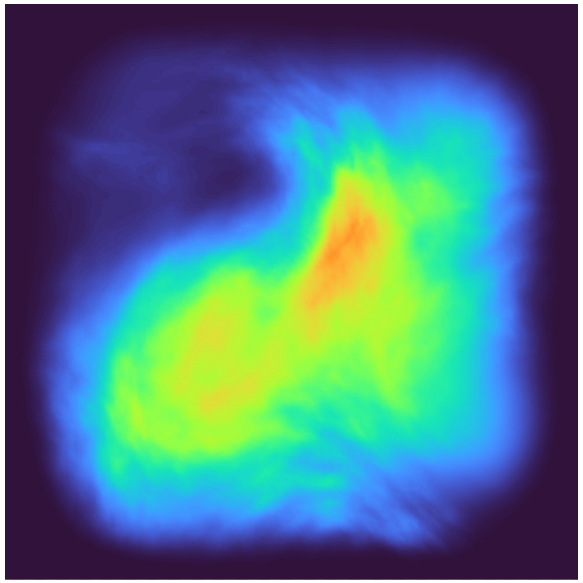
HSUEH-TI DEREK LIU, ROBLOX
YOTAM GINGOLD, GEORGE MASON UNIVERSITY
ALEC JACOBSON, UNIVERSITY OF TORONTO & ADOBE RESEARCH

FAST DIFFERENTIABLE HEIGHTFIELD RENDERER

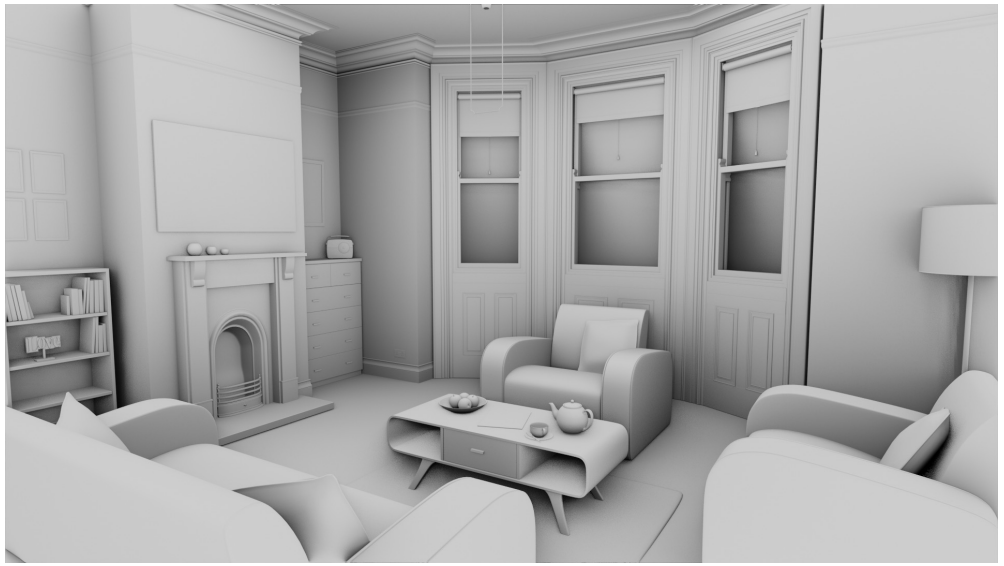


HEIGHTFIELDS

- Geometry representation using 2D scalar fields

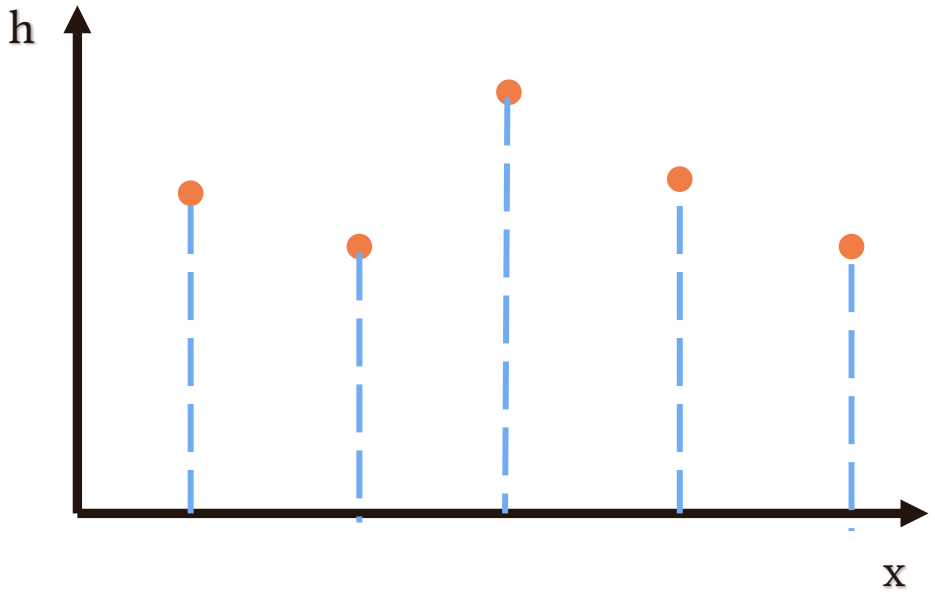


Terrain

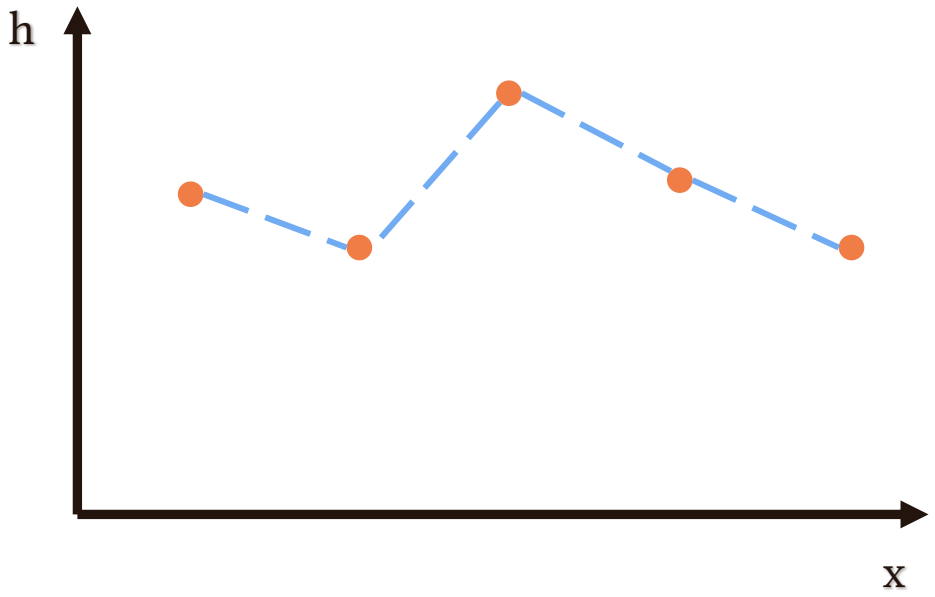


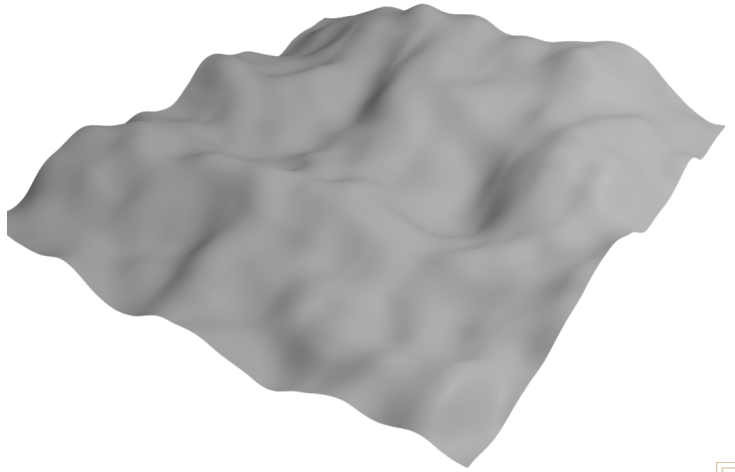
Screen space rendering

DISCONTINUITIES ON HEIGHTFIELD

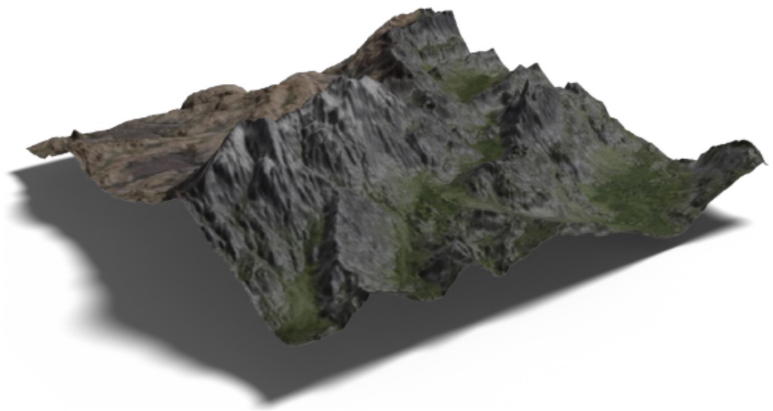


DISCONTINUITIES ON HEIGHTFIELD



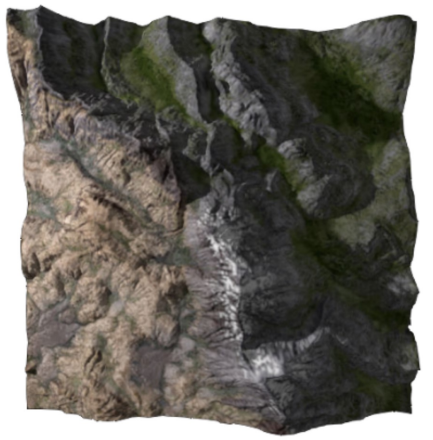


DIFFERENTIABLE HEIGHTFIELD PATH TRACING



Forward pass

Backward pass



optimized rendering

target image

- Light transport equation

$$L_o(\mathbf{x}, \omega_o, h) = L_e(\mathbf{x}, h) + \int_\Omega L_i(\mathbf{x}, \omega_i, h) f(\mathbf{x}, \omega_o, \omega_i, h)\, d\omega_i^\perp$$

- Differentiating continuous integrand is can be done efficiently [Nimier-David et al. 2020; Zeltner et al. 2021]

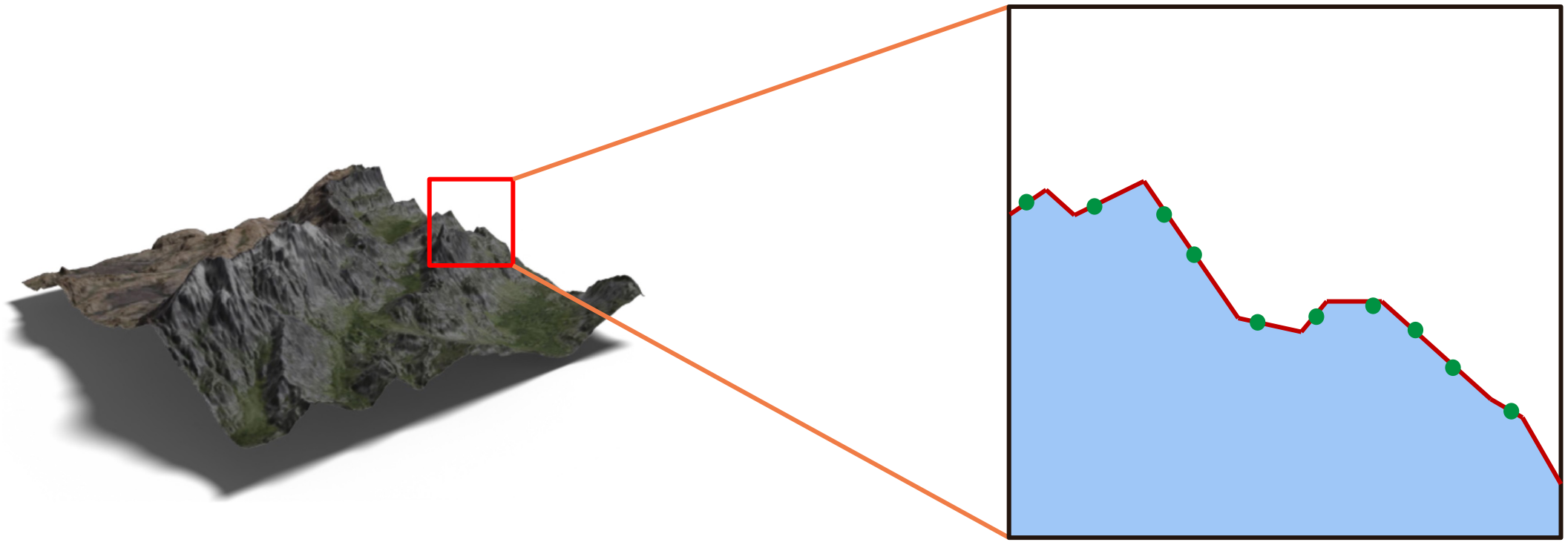
$$\frac{\partial L_o(\mathbf{x}, \omega_o, h)}{\partial h} = \frac{\partial}{\partial h} \int_\Omega L_i(\mathbf{x}, \omega_i, h) f(\mathbf{x}, \omega_o, \omega_i, h) d\omega_i^\perp$$

$$= \int_\Omega \frac{\partial}{\partial h} L_i(\mathbf{x}, \omega_i, h) f(\mathbf{x}, \omega_o, \omega_i, h) d\omega_i^\perp$$

$$+ \int_\Omega \frac{\partial L_i(\mathbf{x}, \omega_i, h)}{\partial h} f(\mathbf{x}, \omega_o, \omega_i, h) d\omega_i^\perp$$

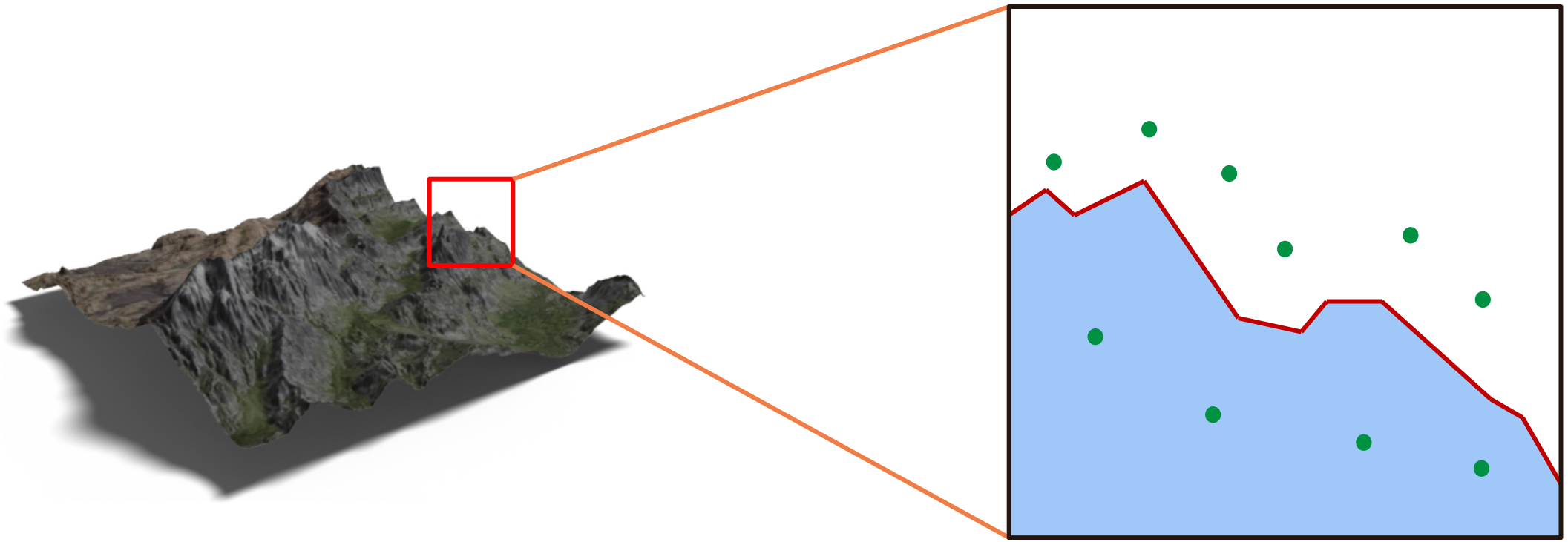
Bottleneck is differentiating discontinuities!

DISCONTINUITIES ON HEIGHTFIELD



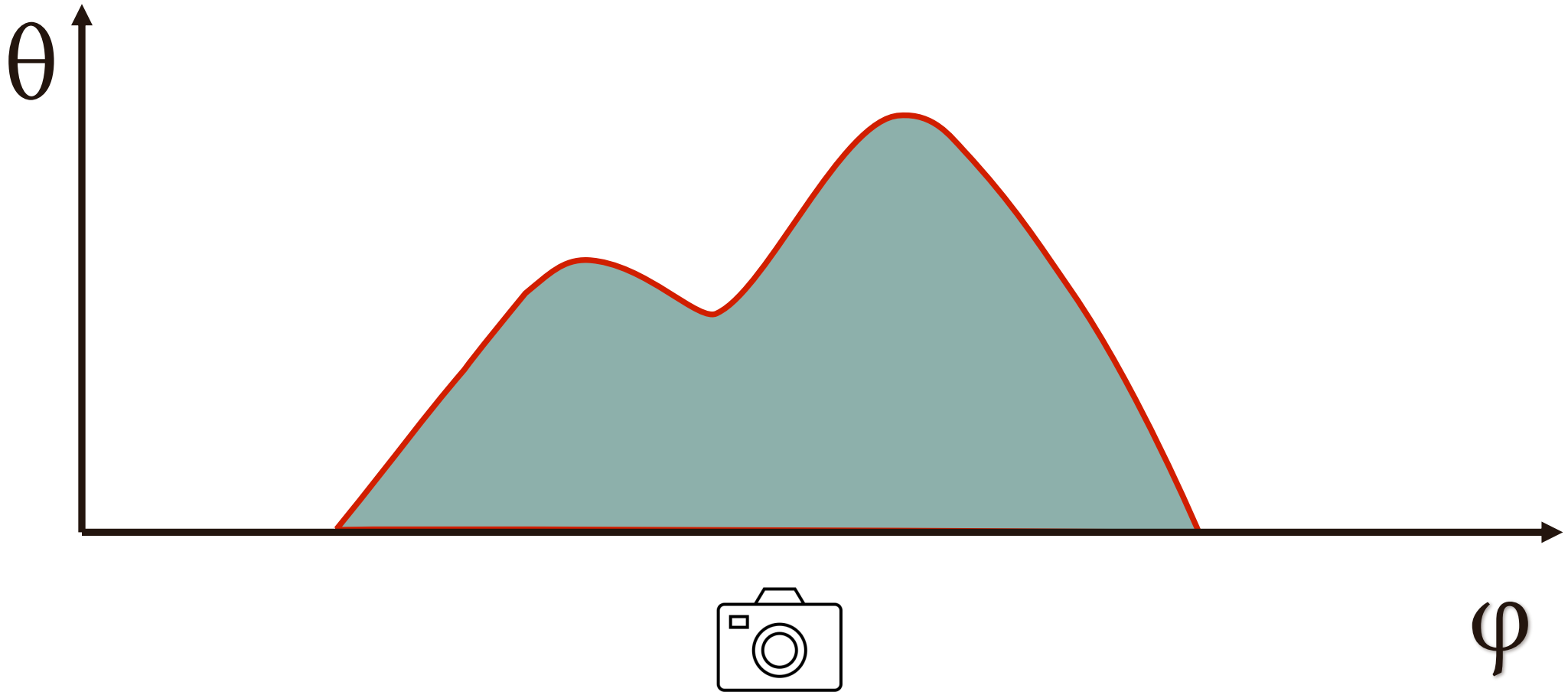
[Li et al . 2018]

DISCONTINUITIES ON HEIGHTFIELD

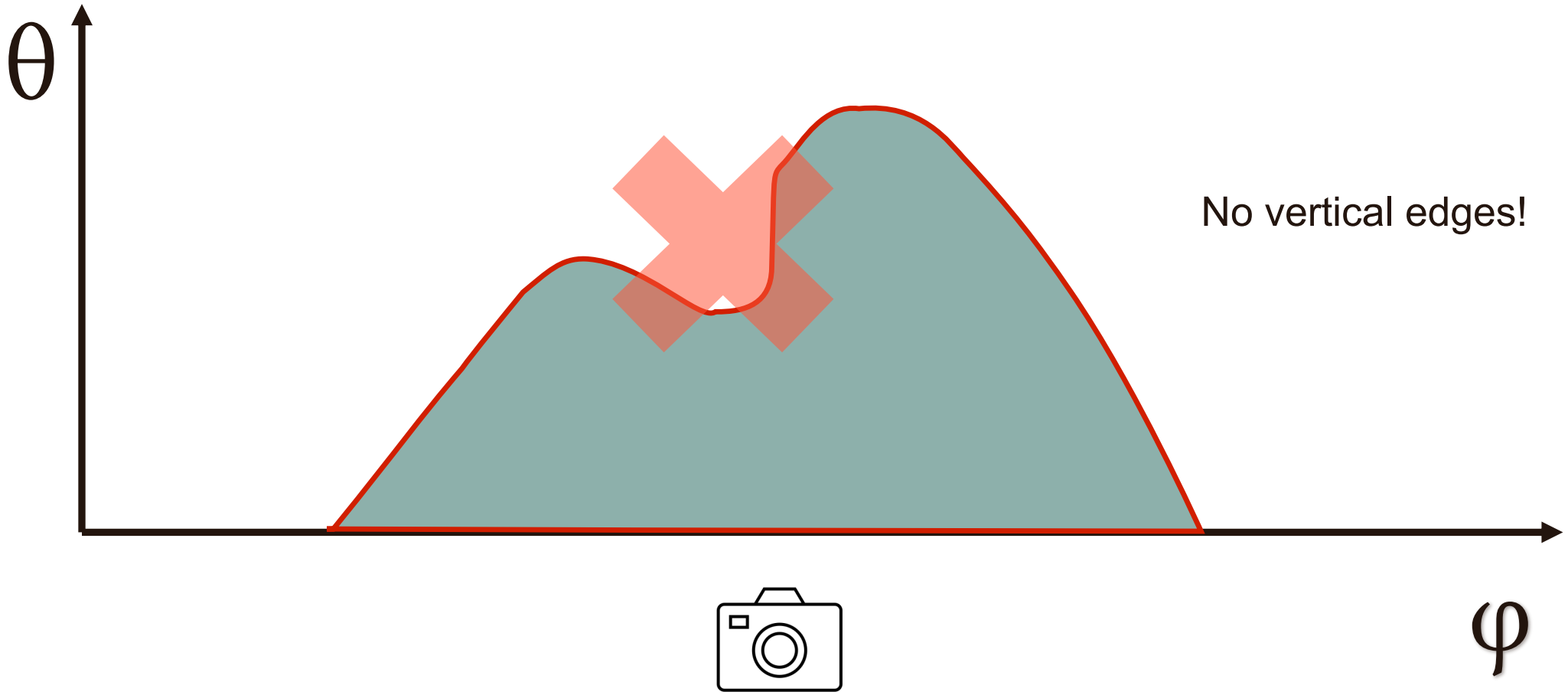


[Loubet et al. 2019]

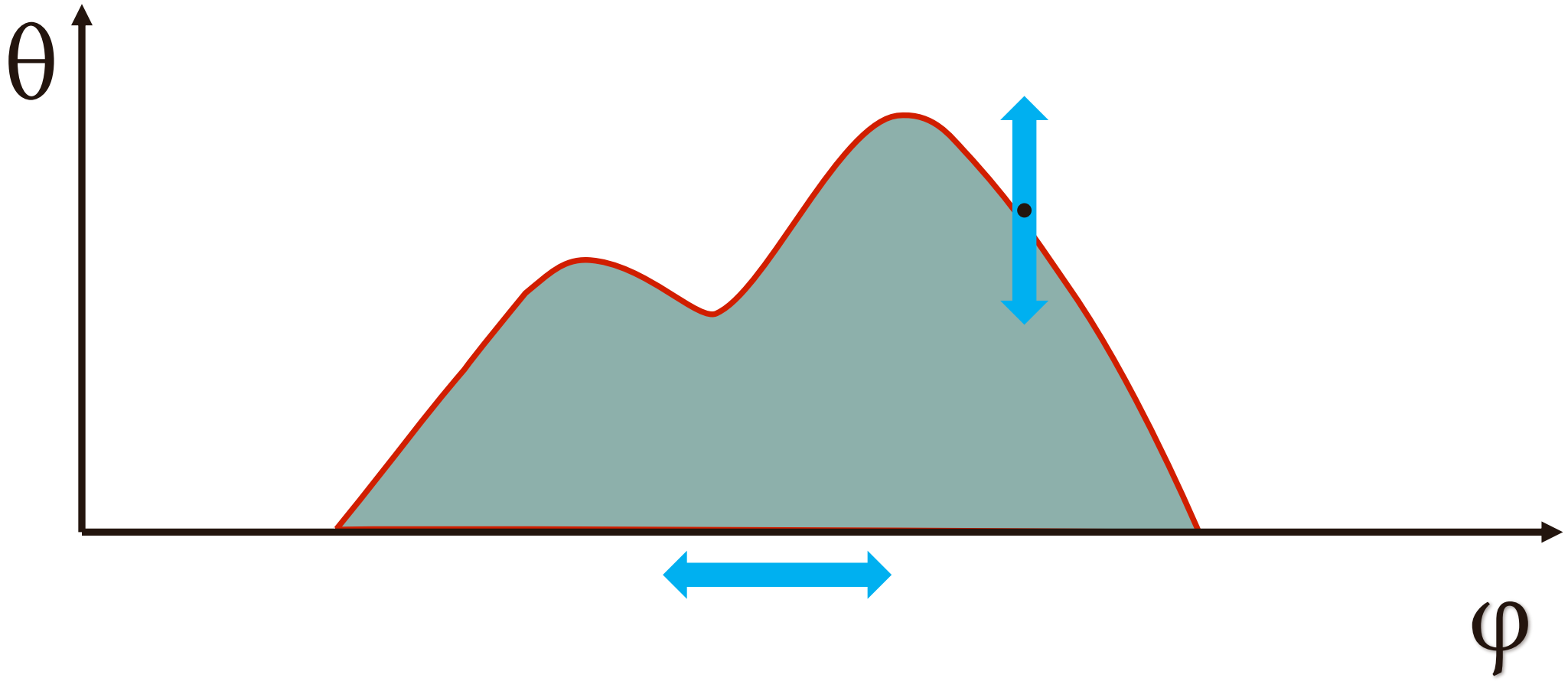
DISCONTINUITIES ON HEIGHTFIELD



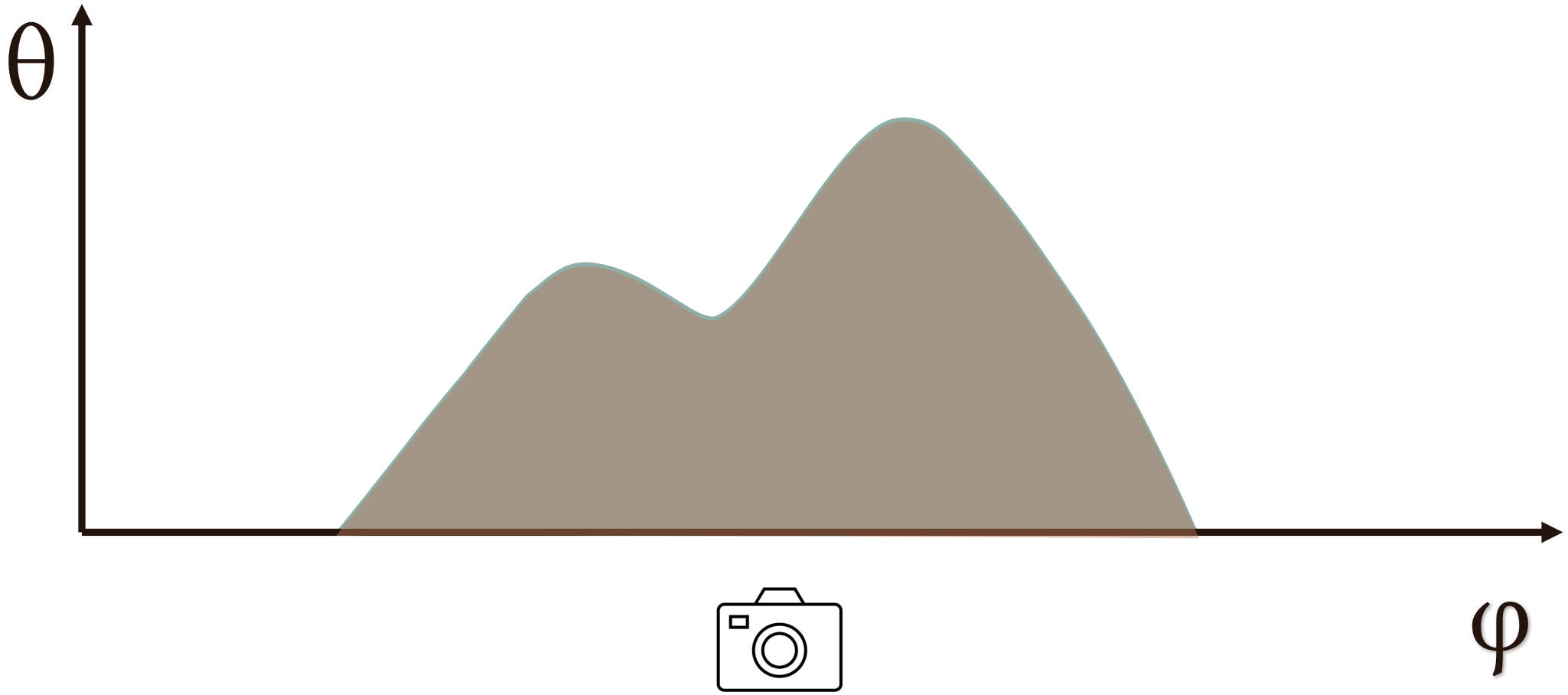
DISCONTINUITIES ON HEIGHTFIELD



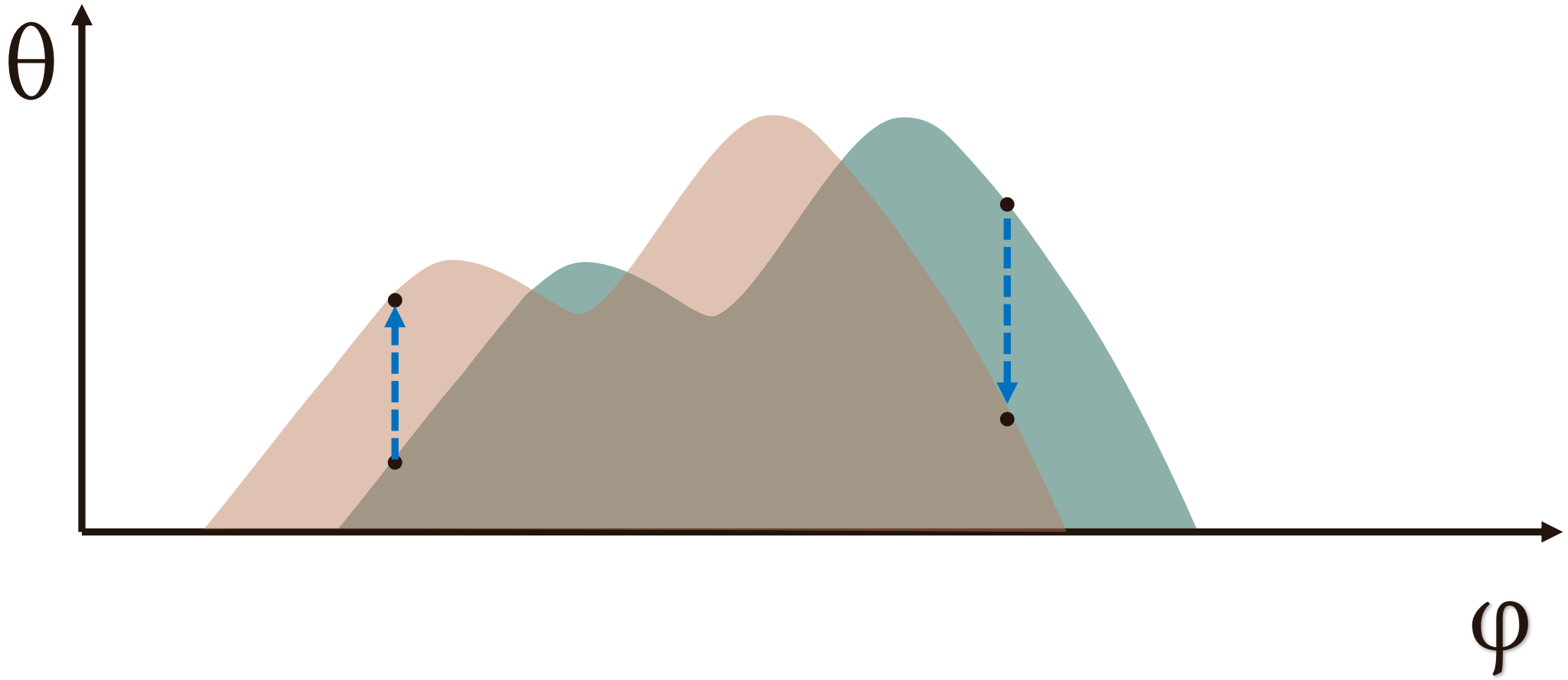
DISCONTINUITIES ON HEIGHTFIELD



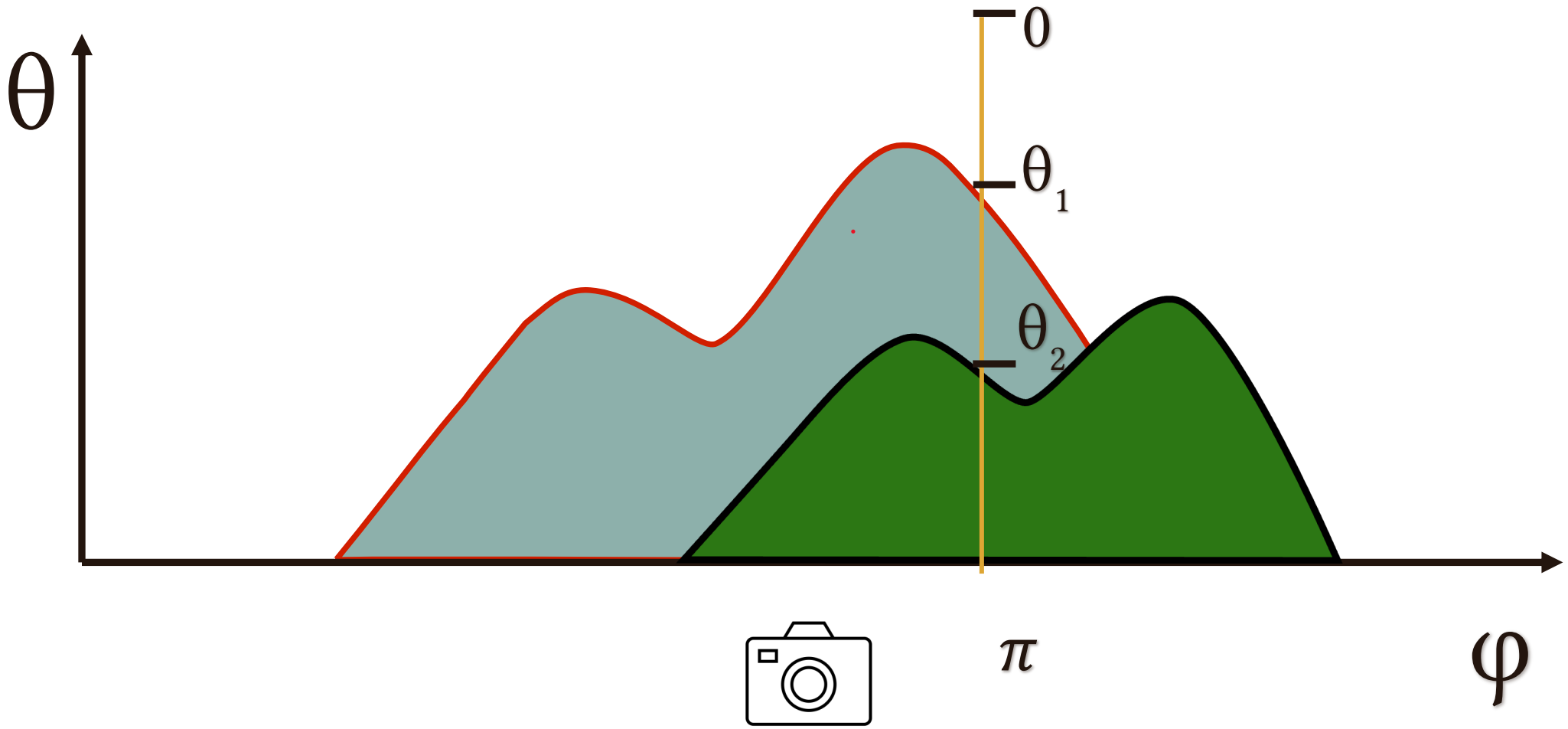
DISCONTINUITIES ON HEIGHTFIELD



DISCONTINUITIES ON HEIGHTFIELD



DISCONTINUITIES ON HEIGHTFIELD



REPARAMETERIZE DISCONTINUITIES

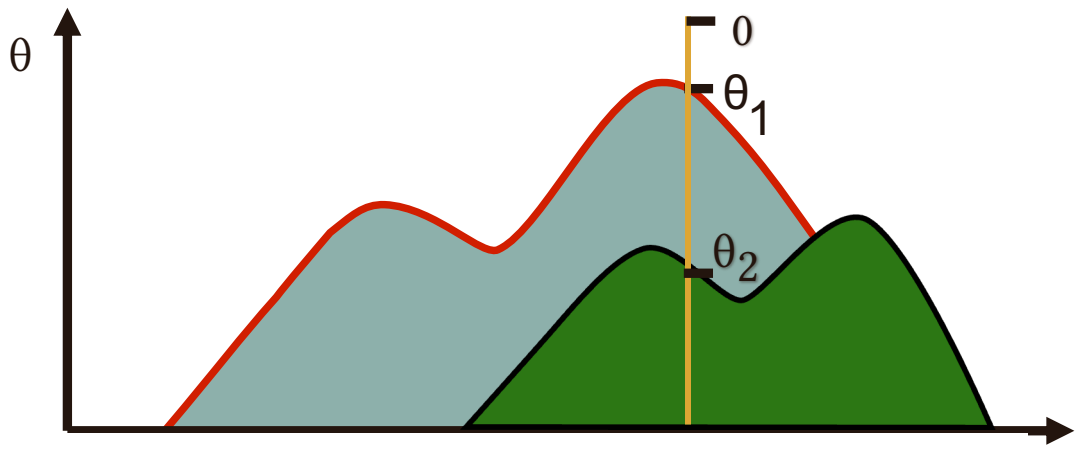
- Reparameterization
  - Make the integral bound independent of scene parameters *h*

$$I = \int_0^{\pi} f(\theta) d\theta$$

$$I = \int_0^{\theta_1} f_1 d\theta + \int_{\theta_1}^{\theta_2} f_2 d\theta + \int_{\theta_1}^{\pi} f_3 d\theta$$

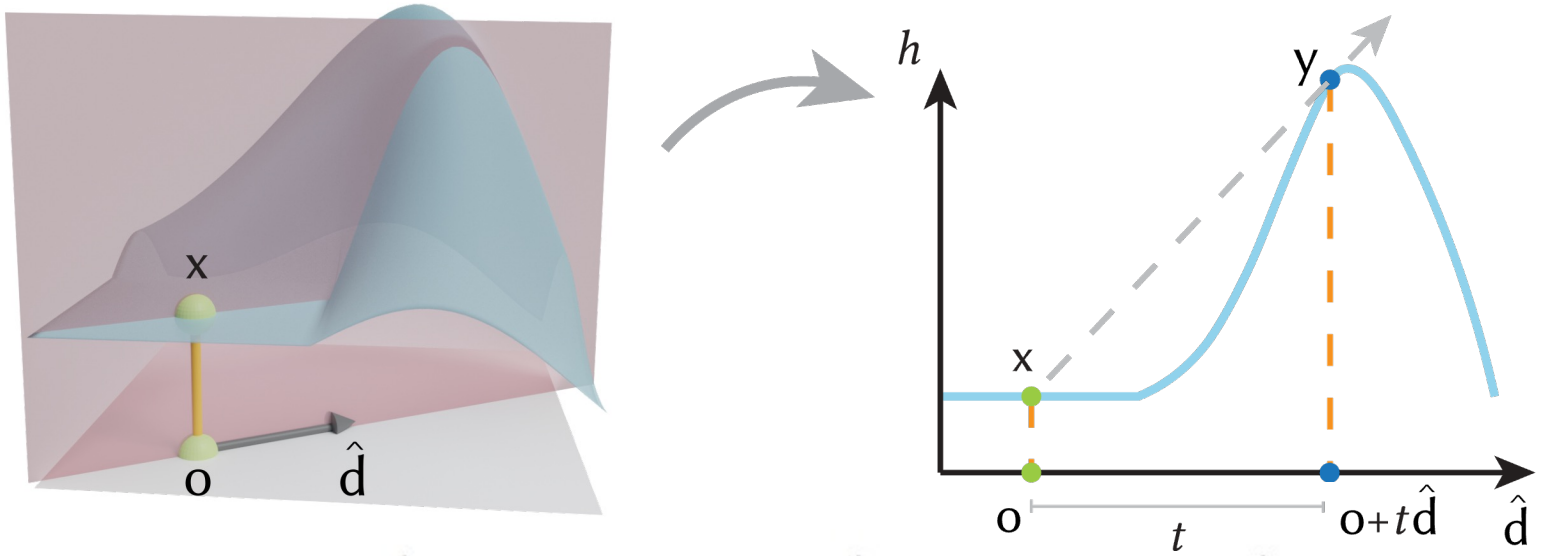
$$T_i(u) = (1-u)\theta_i + u\theta_{i+1}$$

$$I = \int_0^1 f_1 |T_1| du + \int_0^1 f_2 |T_2| du + \int_0^1 f_3 |T_3| du$$



DETERMING DISCONTINUITIES

- Discontinuities are points where ray is tangent to the surface



$$\frac{h(\mathbf{o}+t\hat{\mathbf{d}})-h(\mathbf{o})}{t}=\frac{\partial h(\mathbf{o}+t\hat{\mathbf{d}})}{\partial\hat{\mathbf{d}}}\quad\&\quad\frac{\partial^2 h(\mathbf{o}+t\hat{\mathbf{d}})}{\partial\hat{\mathbf{d}}^2}<0$$

DETERMING DISCONTINUITIES

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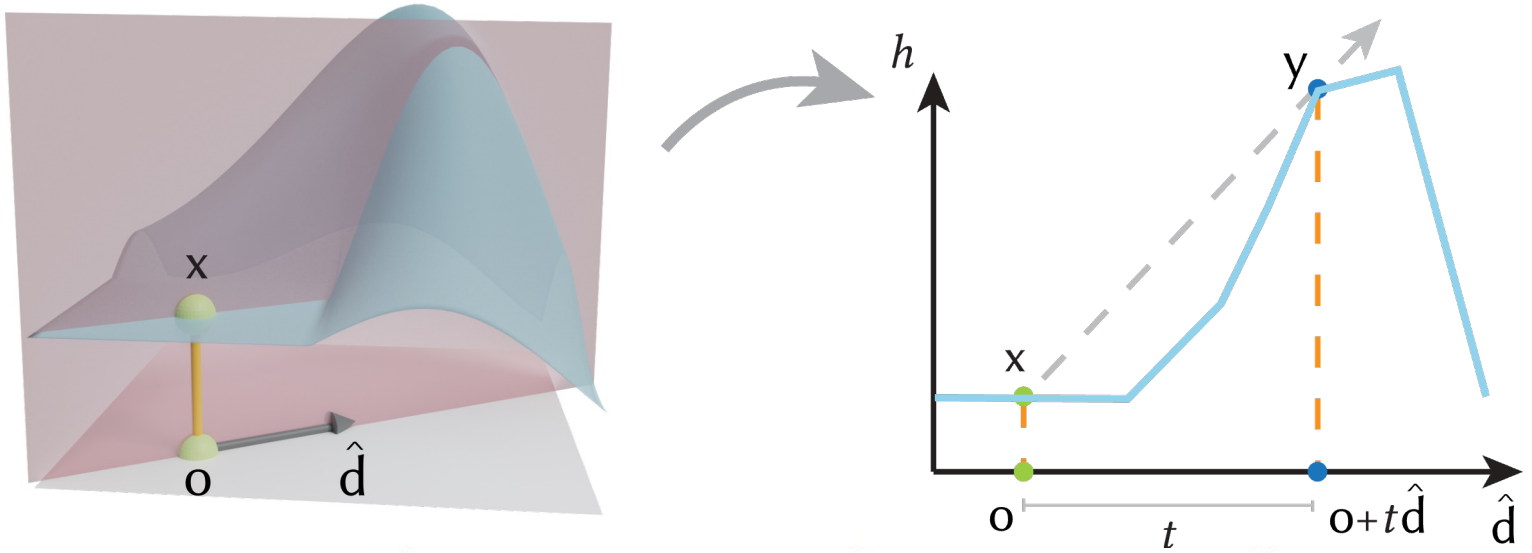
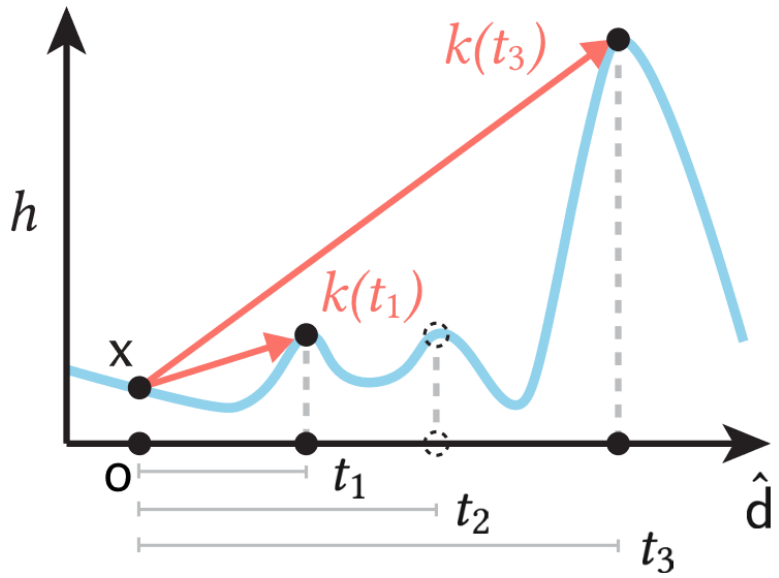


$$\frac{h(\mathbf{o}+t\hat{\mathbf{d}})-h(\mathbf{o})}{t}=\frac{\partial h(\mathbf{o}+t\hat{\mathbf{d}})}{\partial\hat{\mathbf{d}}}\quad\&\quad\frac{\partial^2 h(\mathbf{o}+t\hat{\mathbf{d}})}{\partial\hat{\mathbf{d}}^2}<0$$

ACCELERATE DISCONTINUITY SEARCHING

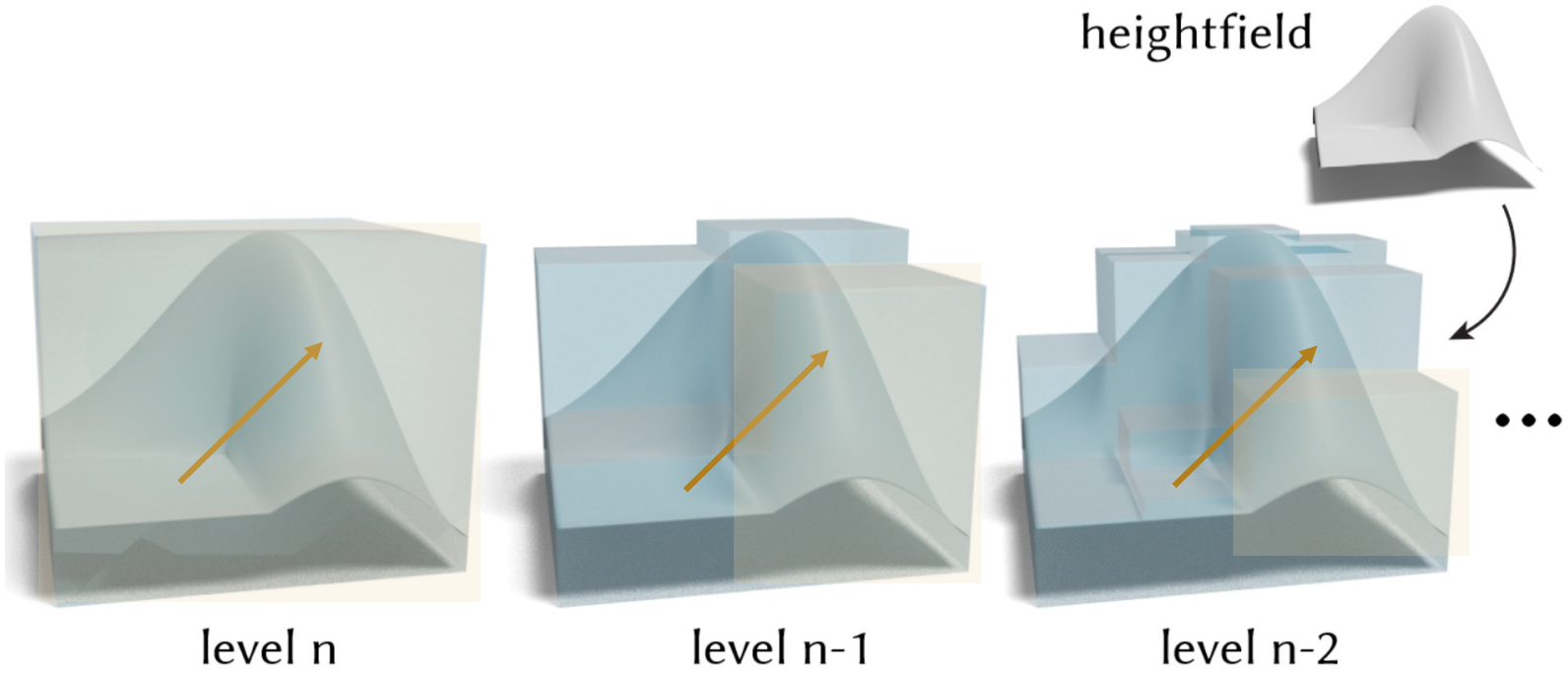
- Lower, further discontinuities are blocked by near higher discontinuities
  - Optimization: track *the current minimum slope* during mipmap ray tracing



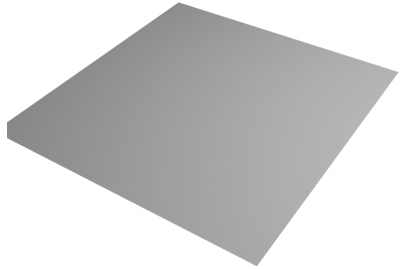
$$k(t) = \frac{h(\mathbf{o} + t\hat{\mathbf{d}}) - h(\mathbf{o})}{t}$$

HEIGHTFIELD (BACKWARD) RENDERING [TODO]

- Skip regions *below* the ray with *current minimum slope*
  - Accelerate with maximum mipmap [Tevset al. 2008]!



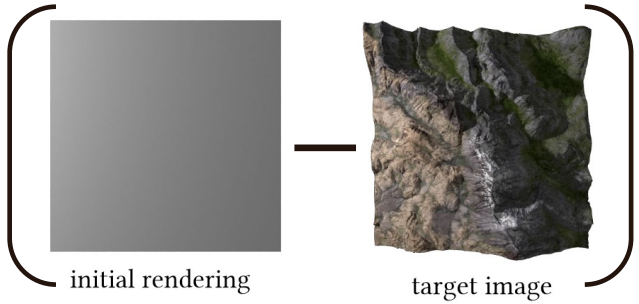
DIFFERENTIABLE HEIGHTFIELD PATH TRACING



initial height field

Forward rendering

Loss

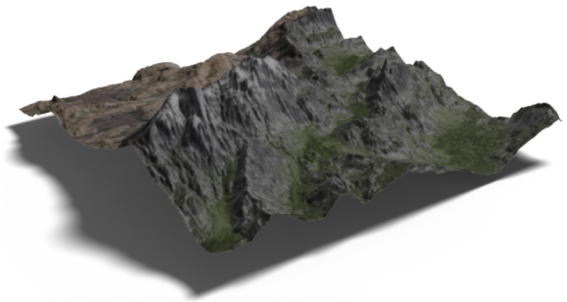


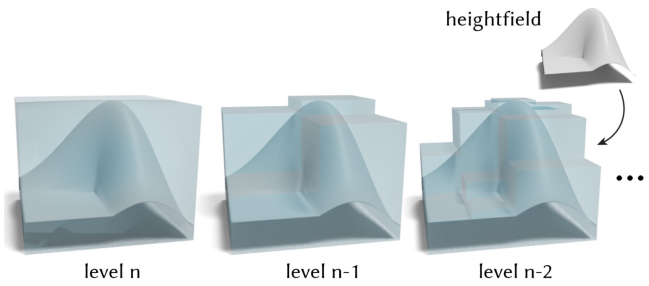
initial rendering

target image

Forward pass

Backward pass

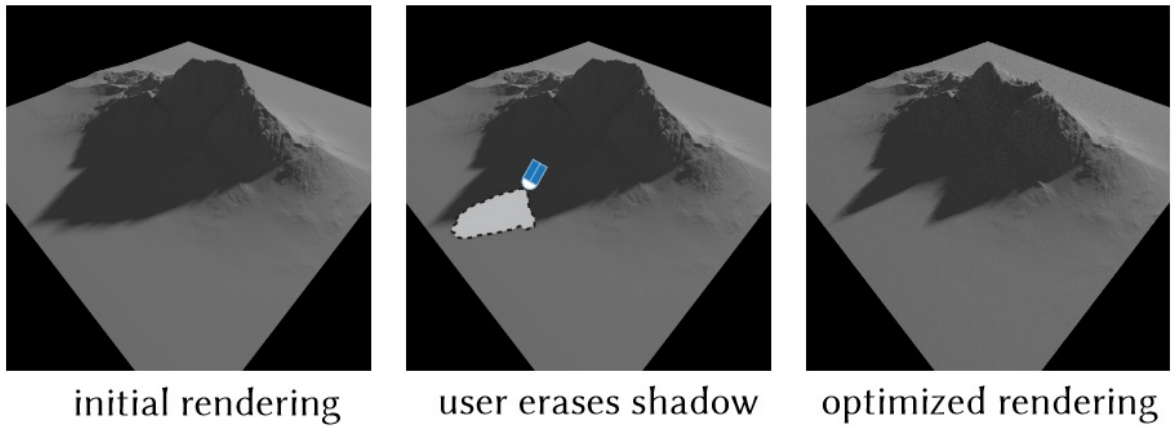


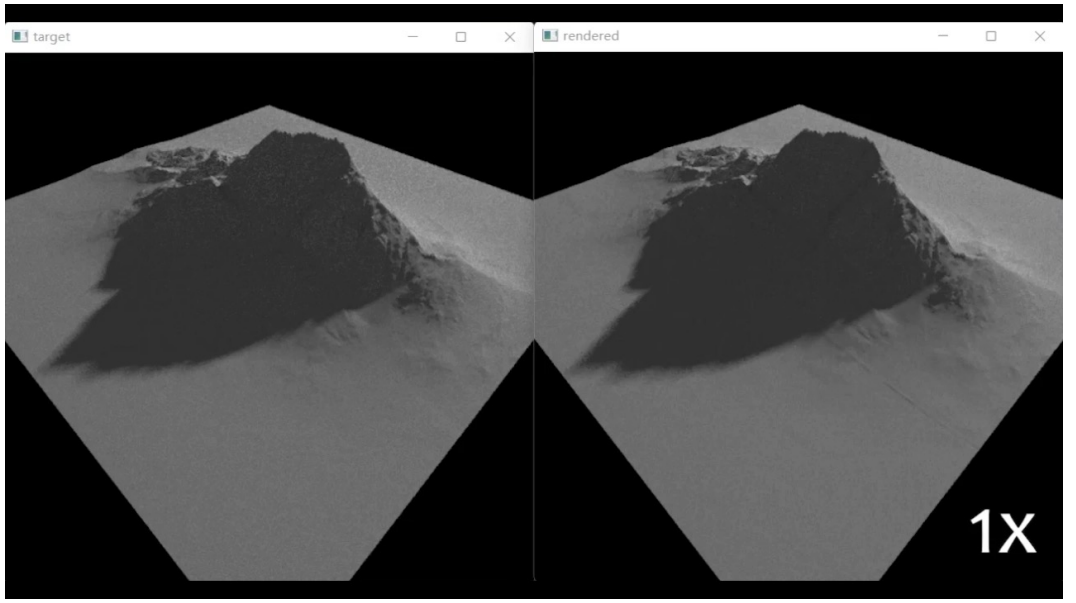


Mipmap accelerated discontinuity searching + reparameterization

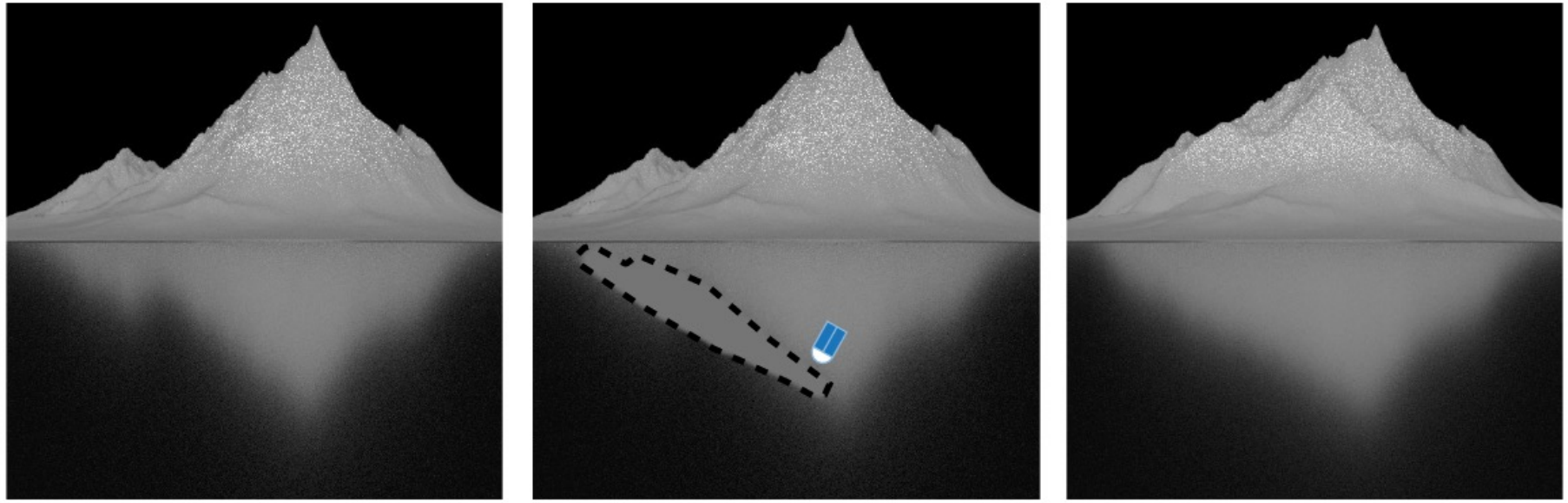
REALTIME SHADOW EDITING

- > 300 spp/s





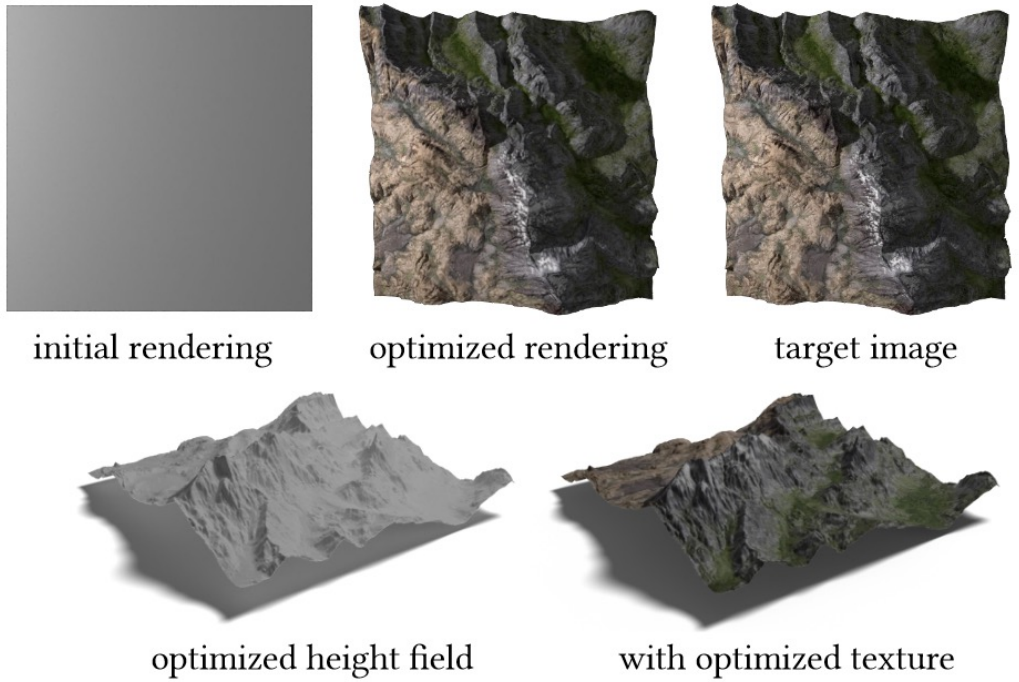
GLOSSY REFLETION EDITING

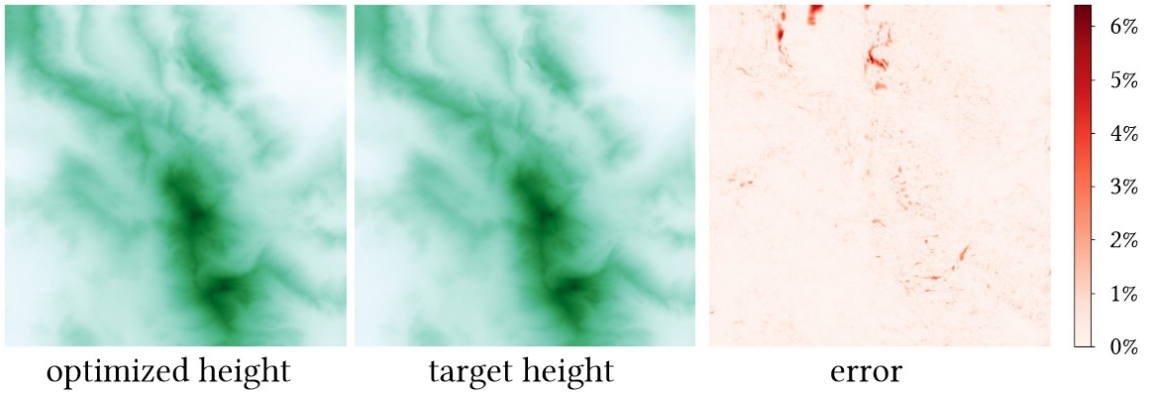


initial rendering user edits reflection optimized rendering

INVERSE RENDERING

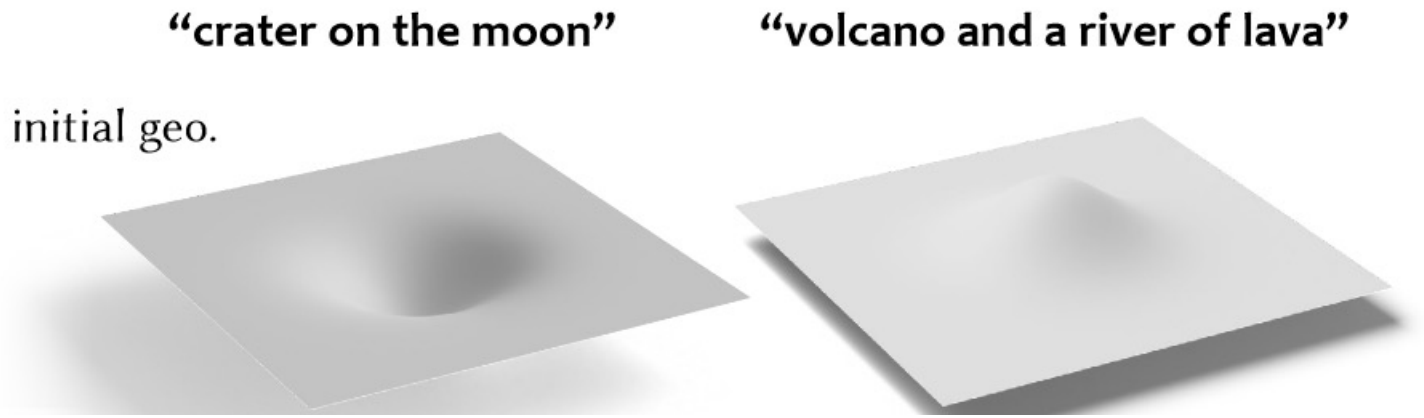
- Multiview surface reconstruction with global illumination





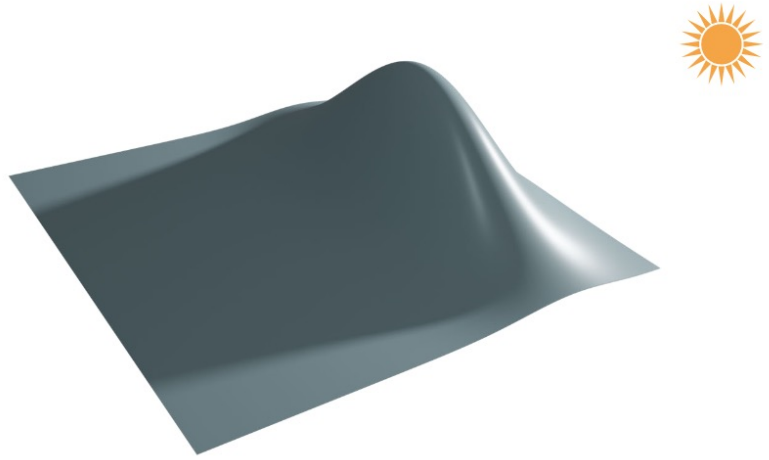
TEXT-TO-SHAPE

- Generate heightfield & material from text prompt using CLIP [Radford et al. 2021]



FUTURE WORK

- Improving convergence rate for glossy material
- Improving performance where scene has few discontinuities
- Explore more interactive applications with differentiable renderers



- Smooth heightfield with few discontinuities

ACKNOWLEDGEMENT

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THANK YOU!

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