DIFFERENTIABLE HEIGHTFIELD PATH TRACING WITH ACCELERATED DISCONTINUITIES

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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
DIFFERENTIABLE HEIGHTFIELD PATH TRACING

- Light transport equation

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

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

\[ \frac{\partial L_o(x, \omega_o, h)}{\partial h} = \frac{\partial}{\partial h} \int_{\Omega} L_i(x, \omega_i, h) f(x, \omega_o, \omega_i, h) d\omega_i^+ \]

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

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

Bottleneck is differentiating discontinuities!
DISCONTINUITIES ON HEIGHTFIELD

[Li et al. 2018]
DISCONTINUITIES ON HEIGHTFIELD

[Loubet et al. 2019]
DISCONTINUITIES ON HEIGHTFIELD

No vertical edges!
DISCONTINUITIES ON HEIGHTFIELD
DISCONTINUITIES ON HEIGHTFIELD
DISCONTINUITIES ON HEIGHTFIELD
DISCONTINUITIES ON HEIGHTFIELD

\[ \theta \]

\[ \varphi \]

\[ \theta_1 \]

\[ \theta_2 \]

\[ \pi \]
Reparameterization

Make the integral bound independent of scene parameters $h$

\[ I = \int_{0}^{\pi} f(\theta) \, d\theta \]

\[ I = \int_{0}^{\theta_1} f_1 \, d\theta + \int_{\theta_1}^{\theta_2} f_2 \, d\theta + \int_{\theta_2}^{\pi} f_3 \, d\theta \]

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

\[ I = \int_{0}^{1} f_1 |T_1| \, du + \int_{0}^{1} f_2 |T_2| \, du + \int_{0}^{1} f_3 |T_3| \, du \]
Discontinuities are points where ray is tangent to the surface

\[
\frac{h(o + t\hat{d}) - h(o)}{t} = \frac{\partial h(o + t\hat{d})}{\partial \hat{d}} \quad \text{and} \quad \frac{\partial^2 h(o + t\hat{d})}{\partial \hat{d}^2} < 0
\]
Discontinuities are points where ray is tangent to the surface

\[
\frac{h(o + t\hat{d}) - h(o)}{t} = \frac{\partial h(o + t\hat{d})}{\partial \hat{d}} \\
&\quad \frac{\partial^2 h(o + t\hat{d})}{\partial \hat{d}^2} < 0
\]
- Lower, further discontinuities are blocked by near higher discontinuities.

- Optimization: track the current minimum slope during mipmap ray tracing.

\[
k(t) = \frac{h(\mathbf{o} + t\mathbf{d}) - h(\mathbf{o})}{t}
\]
• Skip regions below the ray with *current minimum slope*
  
  - Accelerate with maximum mipmap [Tevset al. 2008]!
DIFFERENTIABLE HEIGHTFIELD PATH TRACING

Forward rendering

Loss

initial rendering

target image

initial height field

Mipmap accelerated discontinuity searching + reparameterization

Forward pass

Backward pass
REALTIME SHADOW EDITING

- > 300 spp/s
GLOSSY REFLECTION EDITING

initial rendering  user edits reflection  optimized rendering
Multiview surface reconstruction with global illumination
Generate heightfield & material from text prompt using CLIP [Radford et al. 2021]

“crater on the moon”  “volcano and a river of lava”

initial geo.
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
THANK YOU!

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