A Free-Space Diffraction BSDF (FSD-BSDF)

Team 1

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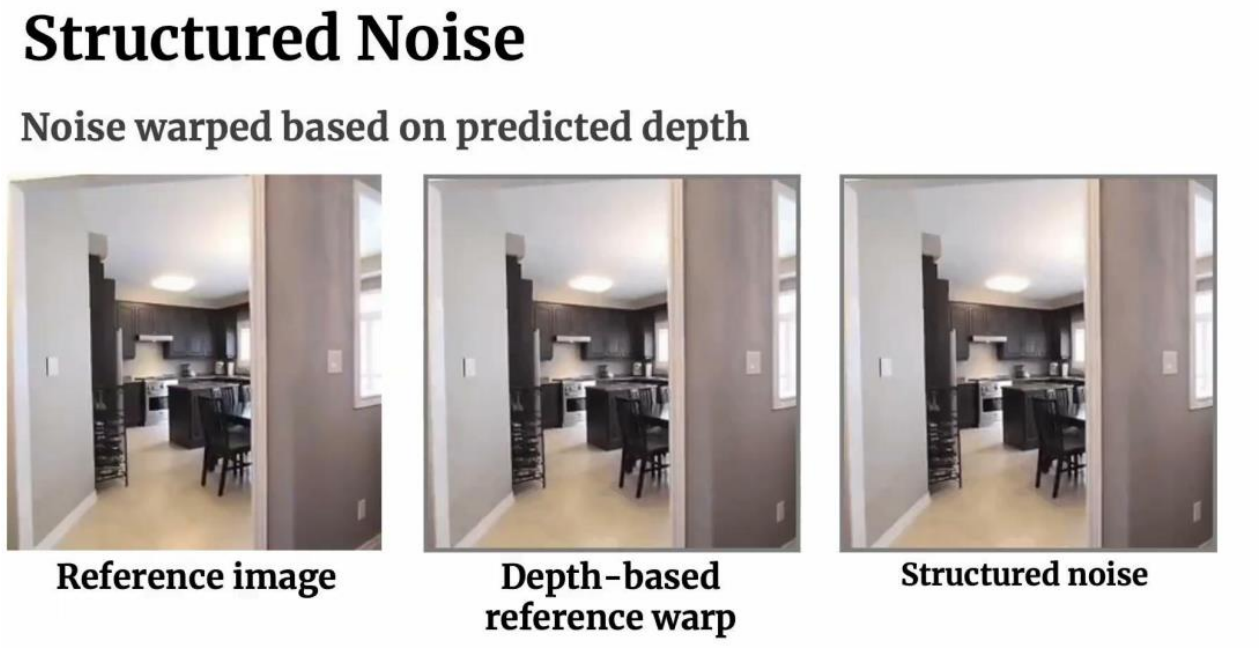
Team 2: MultiDiff

- View synthesis (video) from 1 image using diffusion models
  - Warp colour images based on predicted depth
  - Add structured noise when training
- -> more consistent videos



SIGGRAPH 2024
DENVER+ 28 JUL — 1 AUG

THE PREMIER CONFERENCE
& EXHIBITION ON
COMPUTER GRAPHICS &
INTERACTIVE TECHNIQUES

A FREE-SPACE DIFFRACTION BSDF

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Background

Why is wave optic model important in CG ?

The spinning top in *Inception*

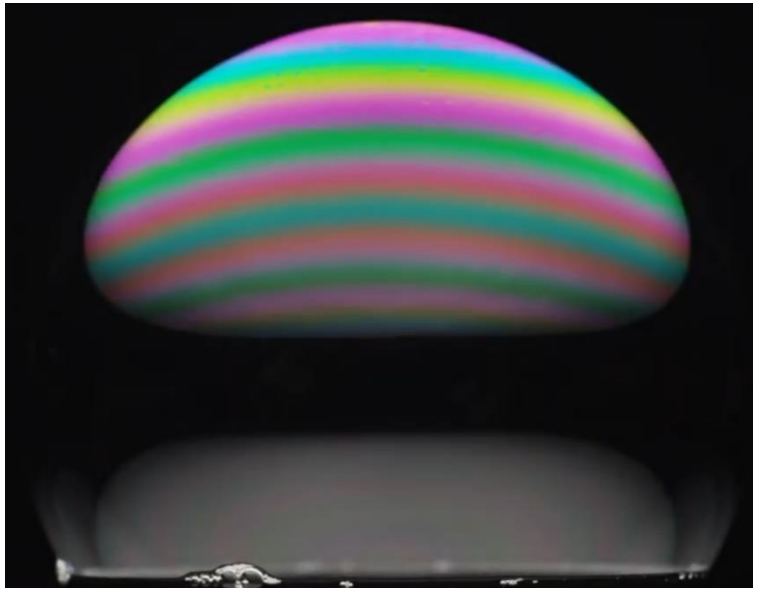
Virtual office designed by protagonists in *Ready Player One*

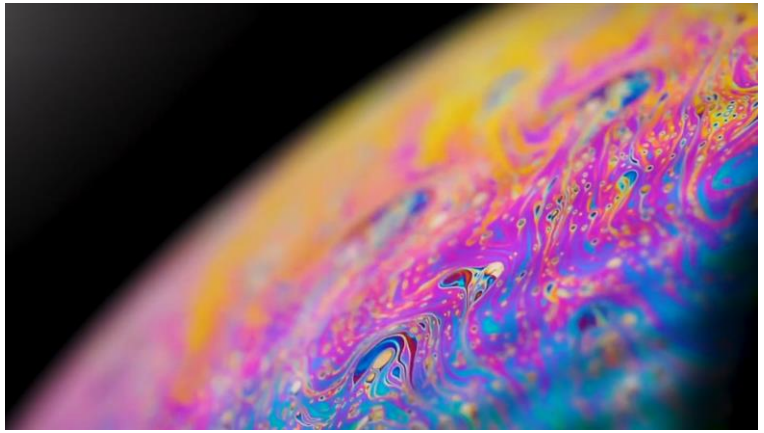
To create a realistic virtual world!

Background

Wave optics in daily life

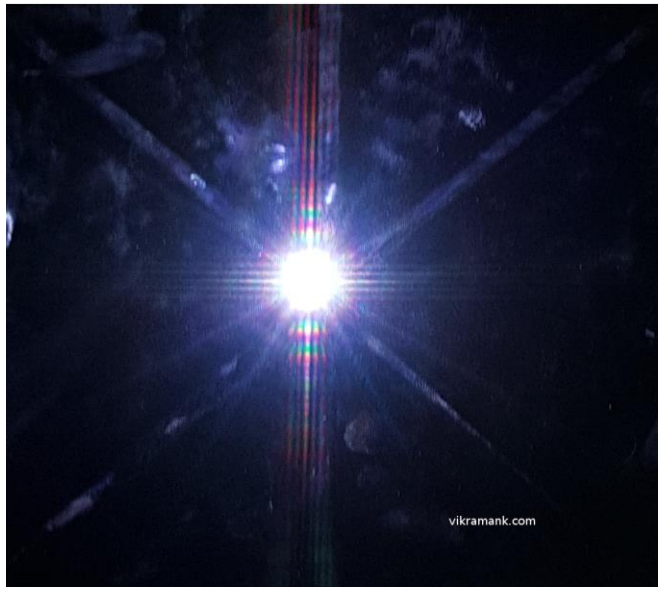
Interference

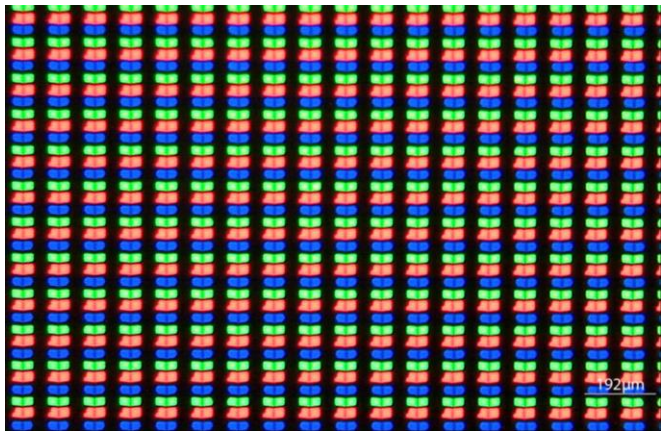




Soap bubble

Diffraction



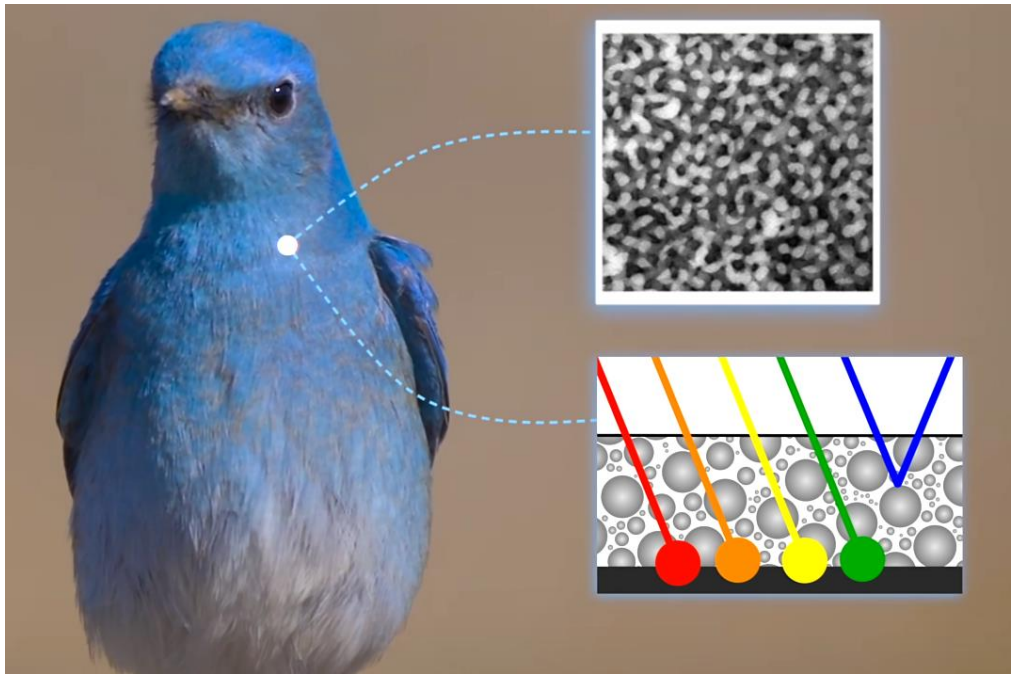


iPad’s screen and the screen under a Microscope

Background

Wave optics in Material Representation

Blue butterfly and the structure of its wings



Bluebird and the structure of its wings

Structural Colors

Credit to *deep look* and (@rogeruzun)

Background

Wave optics in computer graphics

Spiderweb iridescence example

Xia, Mengqi, et al. "A wave optics based fiber scattering model." ACM Transactions on Graphics (TOG) 39.6 (2020): 1-16.

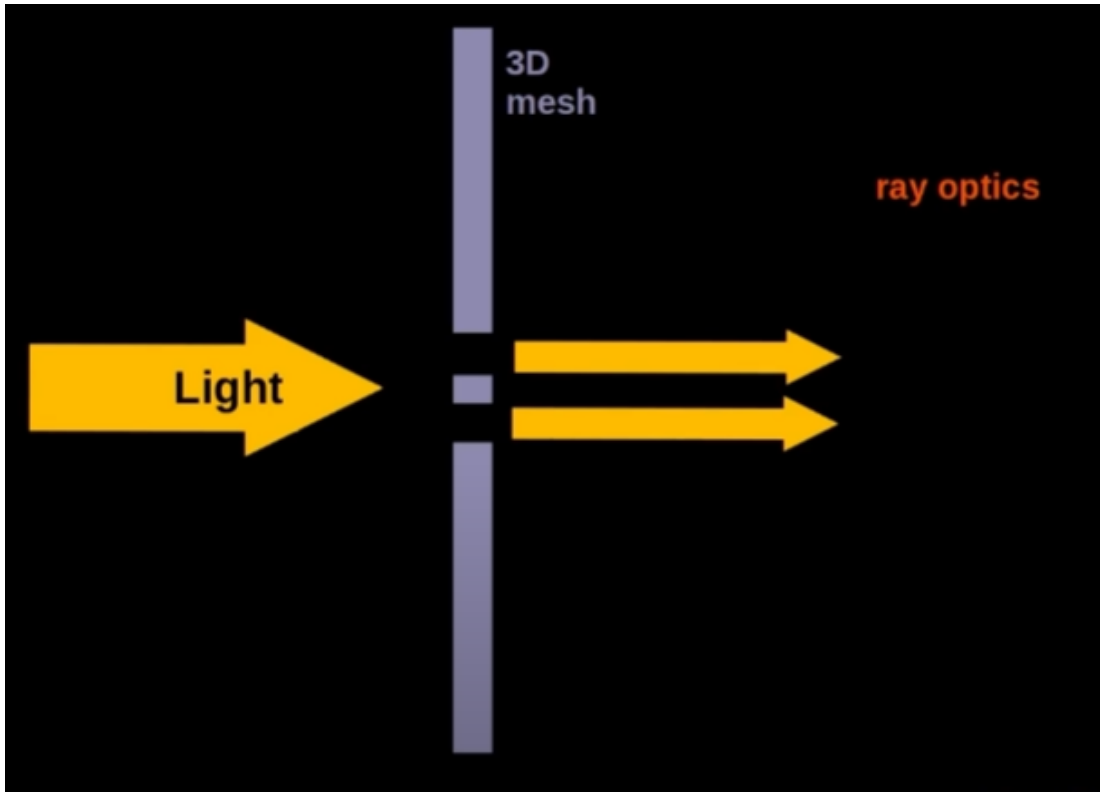
Models of Light

- **Quantum optics**
  - Fundamental model of the light
  - Explain the dual wave-particle nature of light
- **Wave model**
  - Simplified quantum optics
  - Explains diffraction, interference, and polarization

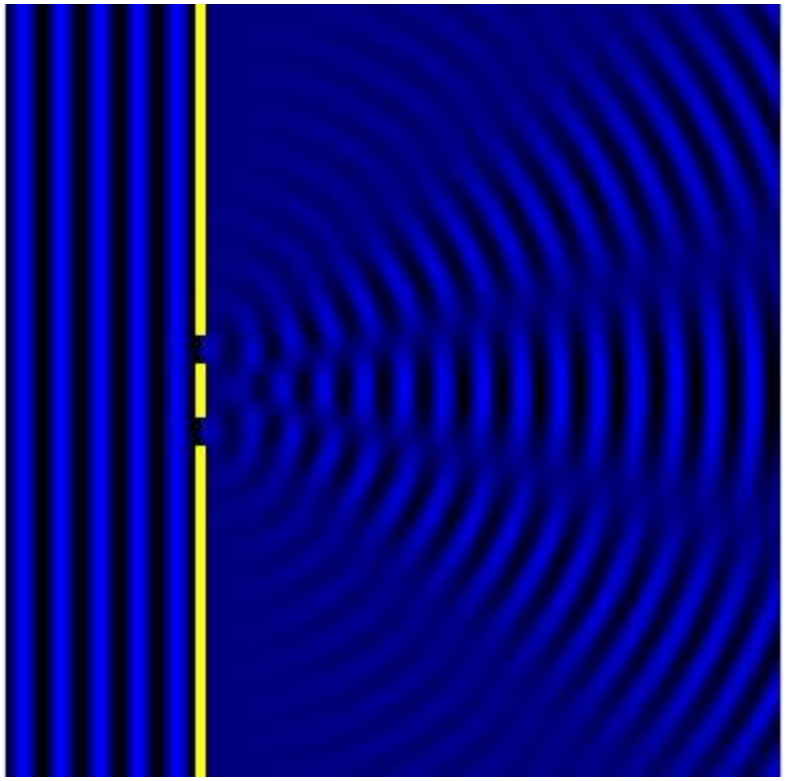
- **Geometric optics**
  - Most commonly used model in CG
  - Size of objects >> wavelength of light
  - Light is emitted, reflected, and transmitted

Background

What is diffraction?



A simple mesh with a couple of openings cut out in the center

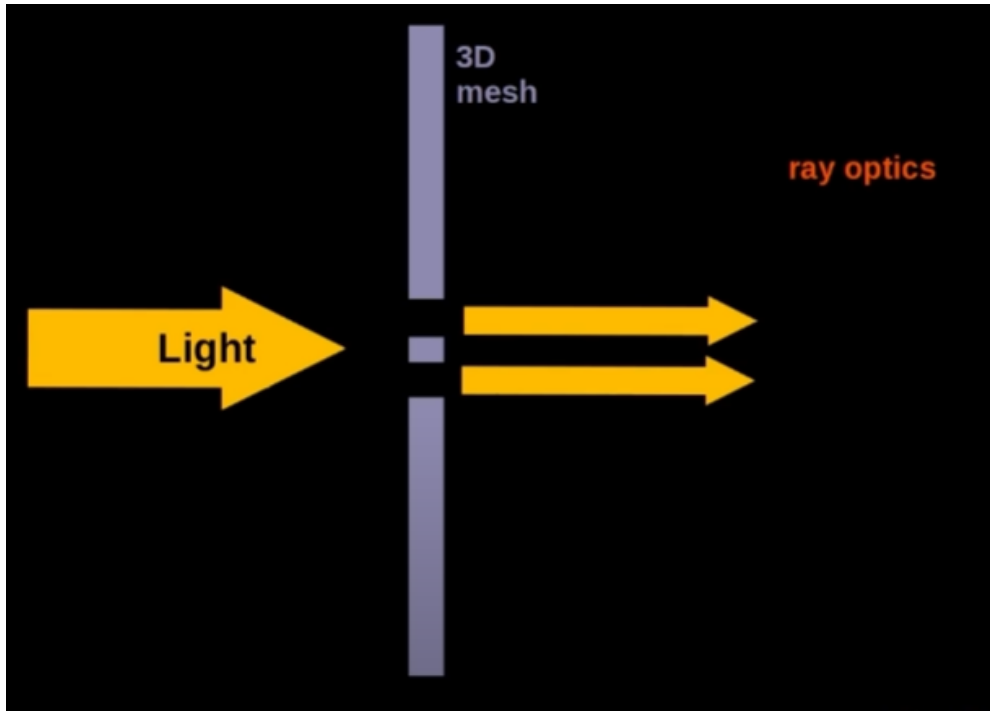


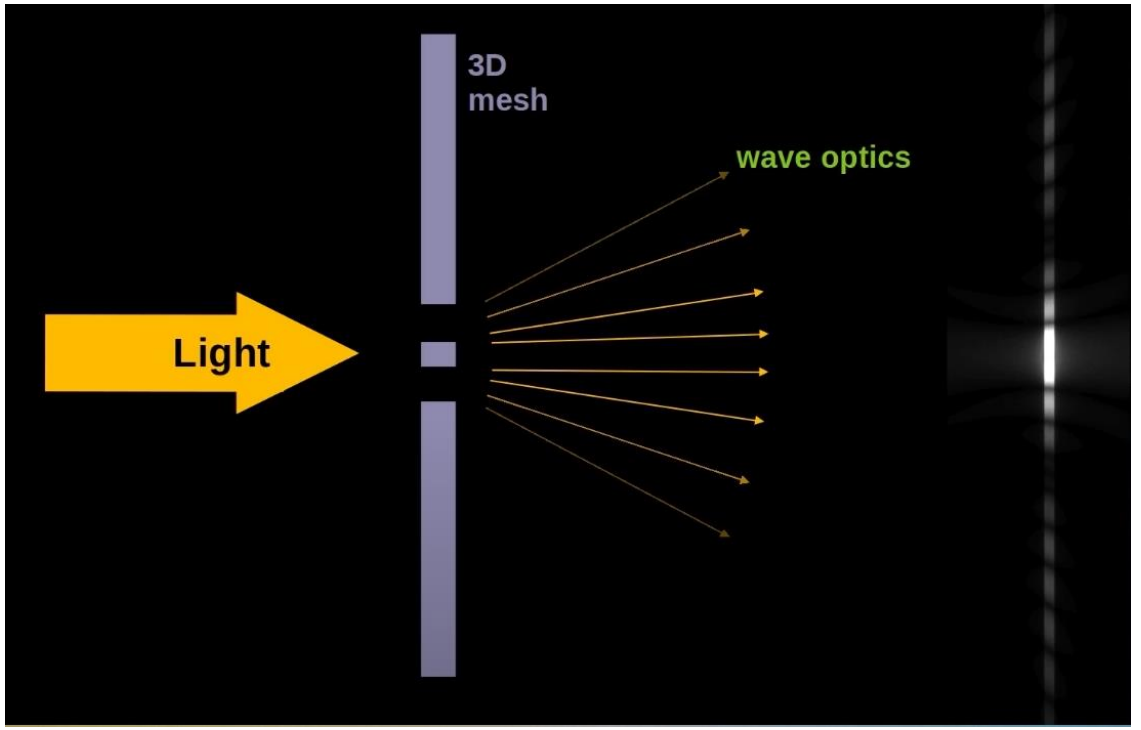
Light is an electromagnetic wave

Diffraction: wave deviates from the original straight line propagation when it encounters an obstacle.

Background

What is diffraction?

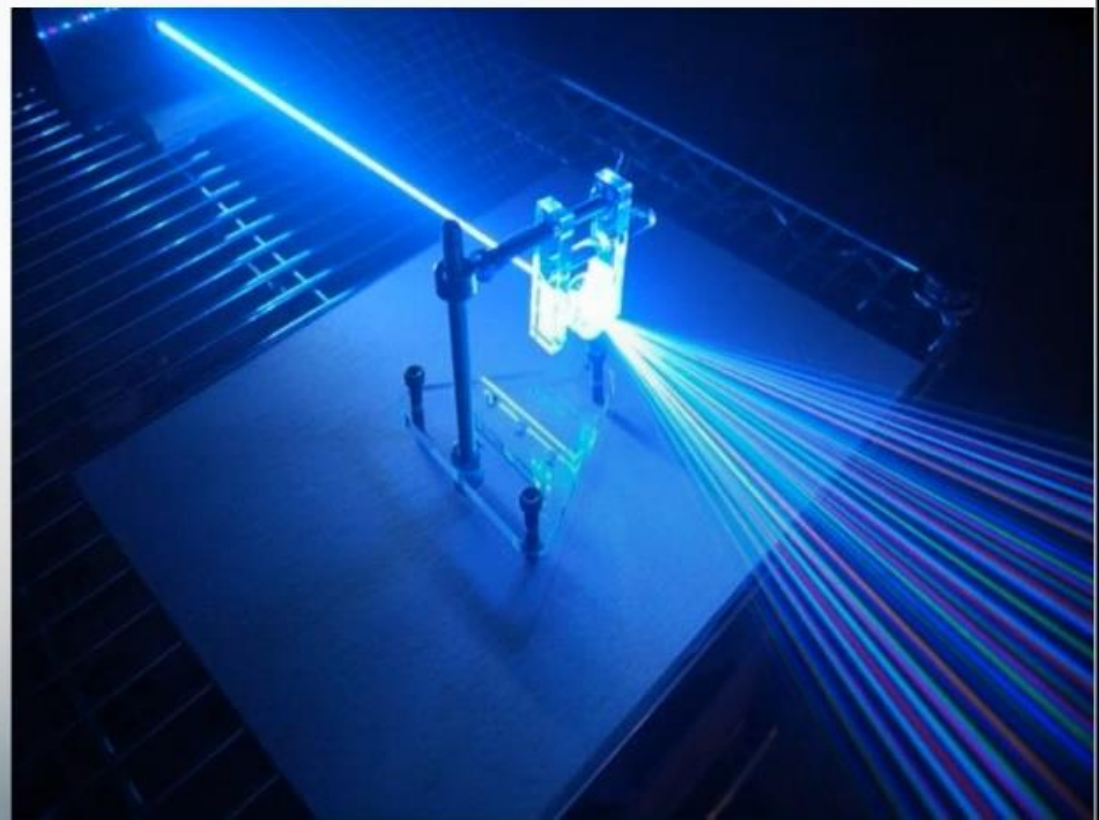




Background

What is diffraction?

- Light consists of electromagnetic waves
  - Optical and non-optical frequencies
- Diffracts – *bends* – around objects and geometry
- Happens with **all** objects and edges in the scene



Background

Why ?

- Wave-optical simulations
- Medical devices
- Simulation of EM radiation
  - IR, X-Ray, Cellular, WiFi, RADAR, GPS, etc.
- Acoustics

Background

Why ?

Compute the signal coverage of cellular in a city

Background

Why ?

Previous Methods

In CG

- Precompute BSDFs for a particular aperture [Reflectance model for diffraction]
- Highly specific, doesn’t generalize

Computational optics

- GTD/UTD (Geometric/uniform theory of diffraction)— non linear transport
  - Used in CG as well.
  - Mutually interfering rays
- Does not scale

Cuypers, Tom, et al. "Reflectance model for diffraction." *ACM Transactions on Graphics (TOG)* 31.5 (2012): 1-11.

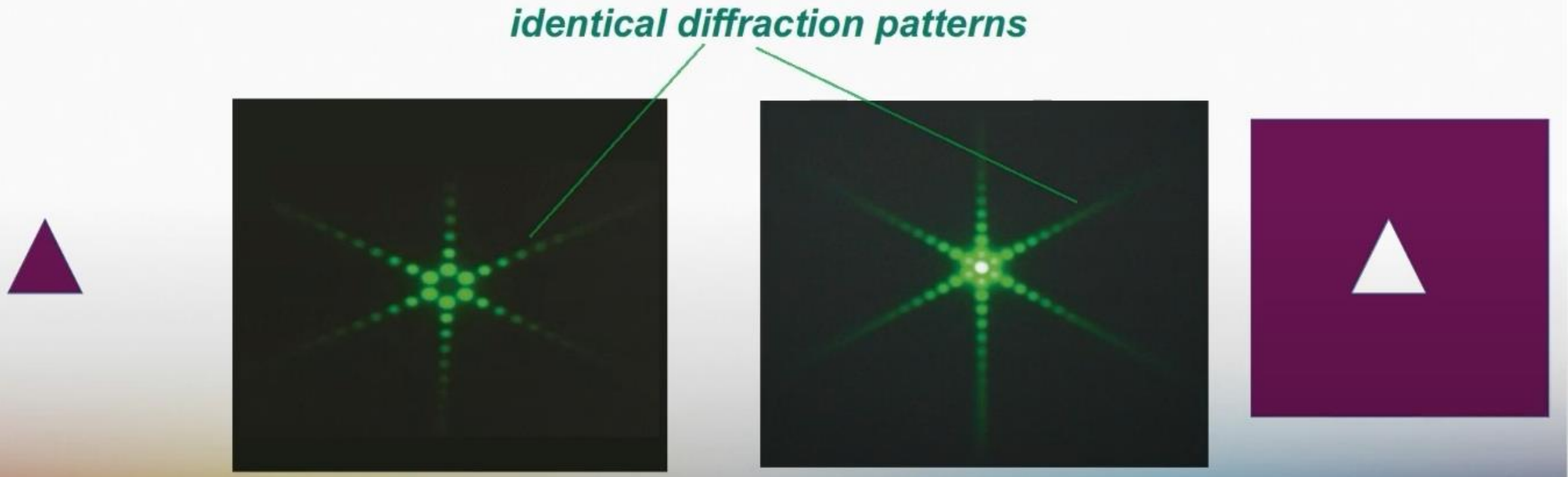
Methods

Their method:

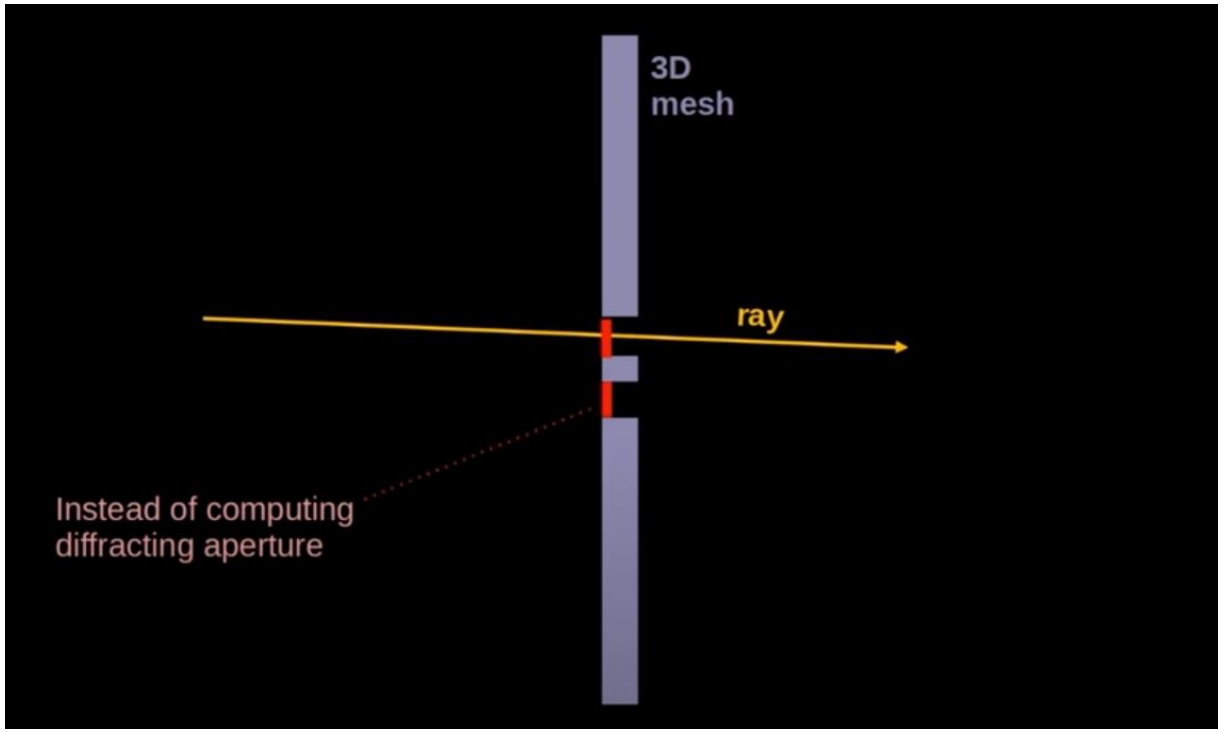
- **Ray tracing only**
- Arbitrary triangular meshes
  - Diffraction around **all** objects
- No pre-computations
- Accurate diffraction lobes

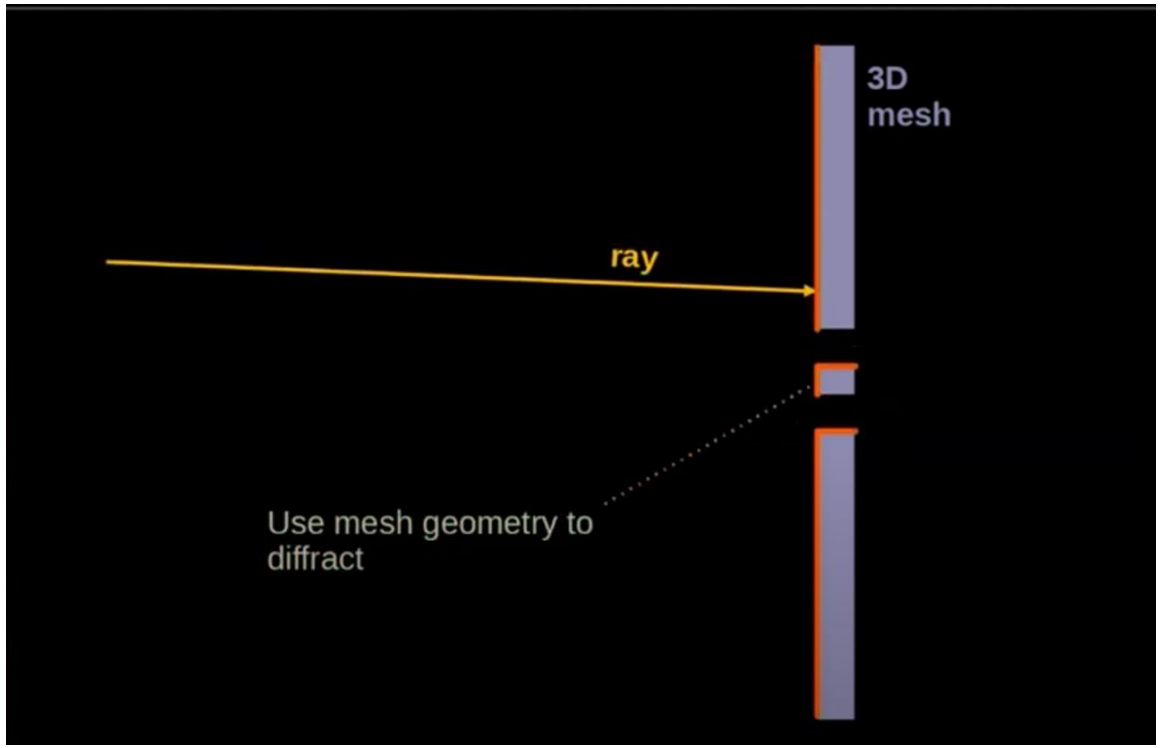
Babinet's Principle

- **Babinet's Principle:** Diffraction by geometry and its complement produce identical diffraction patterns.



Methods

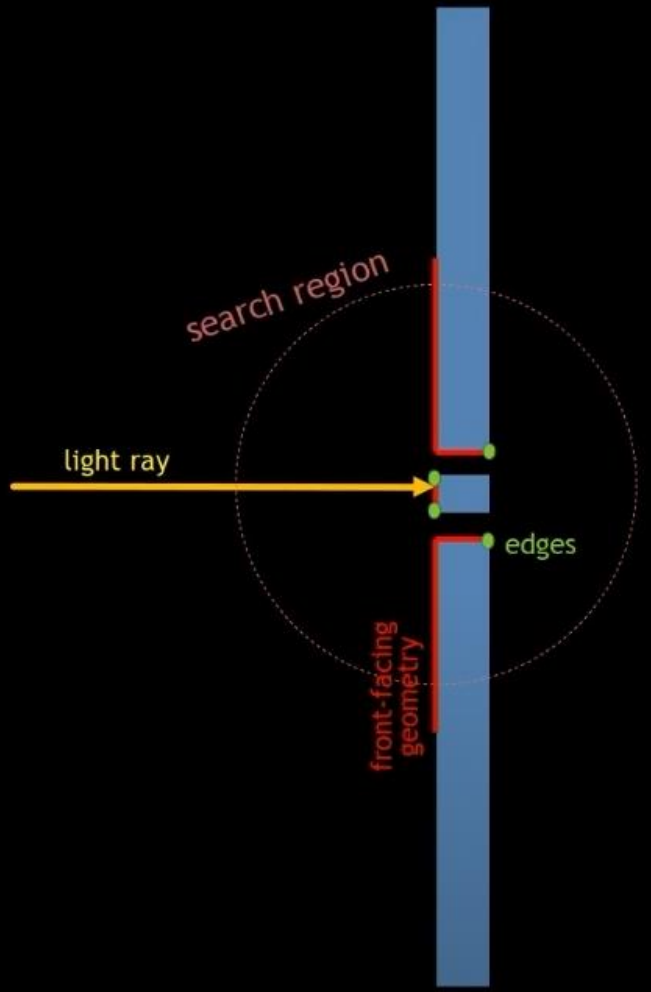

3D
mesh
ray
Instead of computing
diffracting aperture


3D
mesh
ray
Use mesh geometry to
diffract

- **Idea**
  - Ray trace
  - When a ray falls upon geometry, use the geometry itself for diffraction
    - Babinet’s principle: correct diffraction lobes

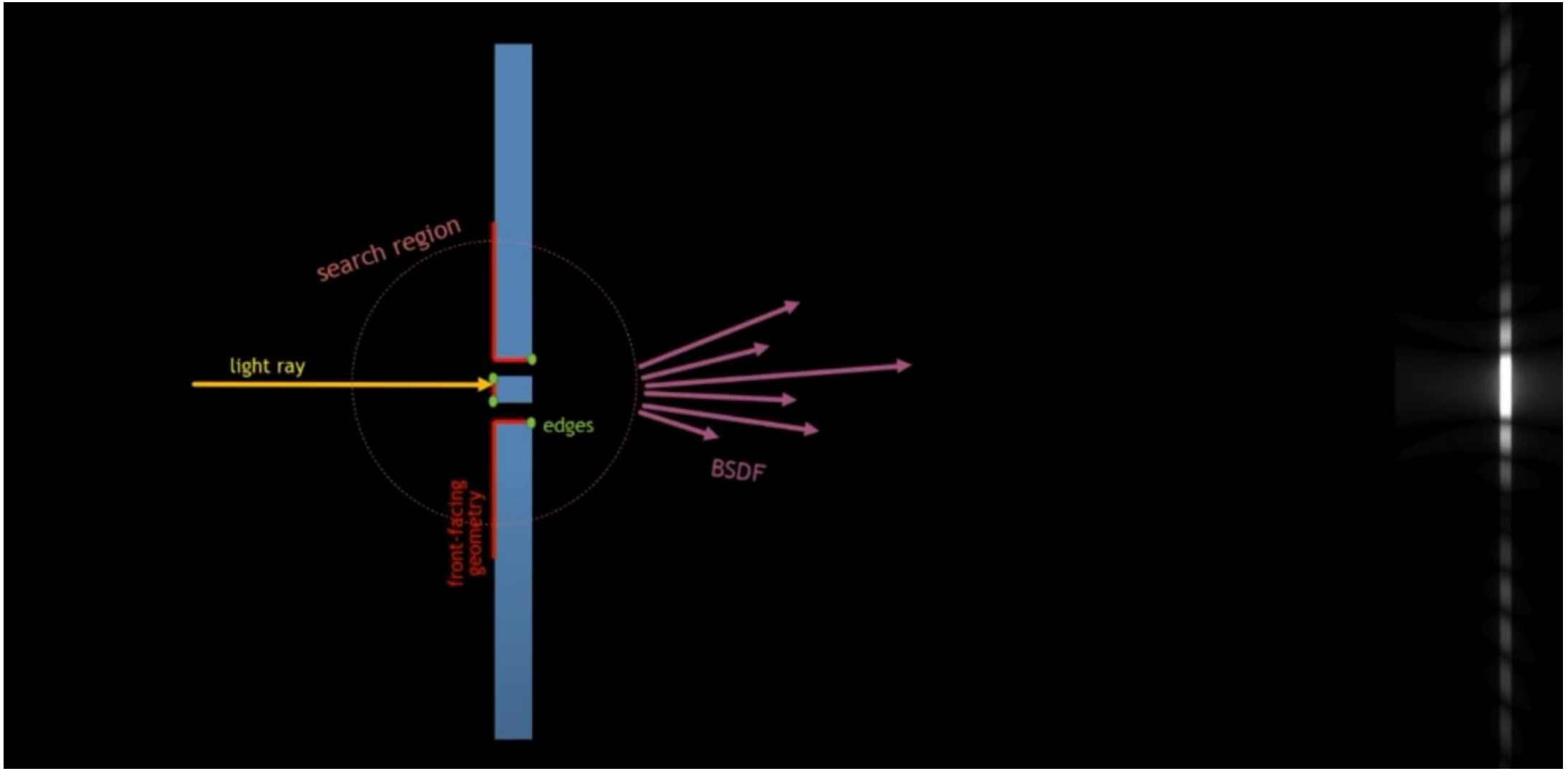
- **Primary formal contribution**
  - Closed-form Fraunhofer diffraction with arbitrary triangular mesh
  - Arbitrary (smooth) wavefunctions
- Enables the construction of **free-space diffraction BSDFs**

Methods

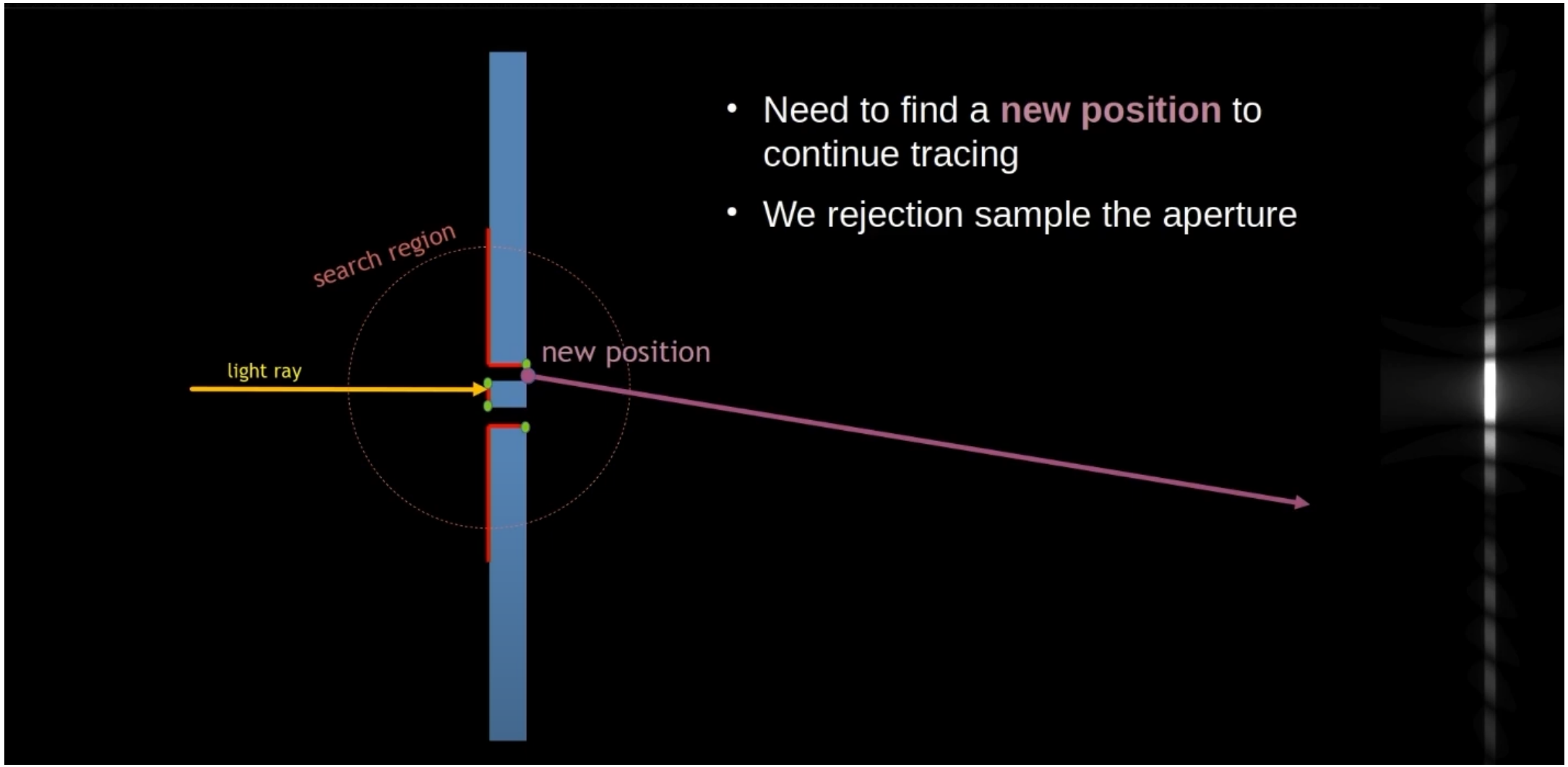


- From list of edges, we derive a **Free-Space Diffraction BSDF**
  - Uses closed-form expression for **Frauhofer diffraction**
  - **Importance sampling** strategy
  - Linear time construction and evaluation

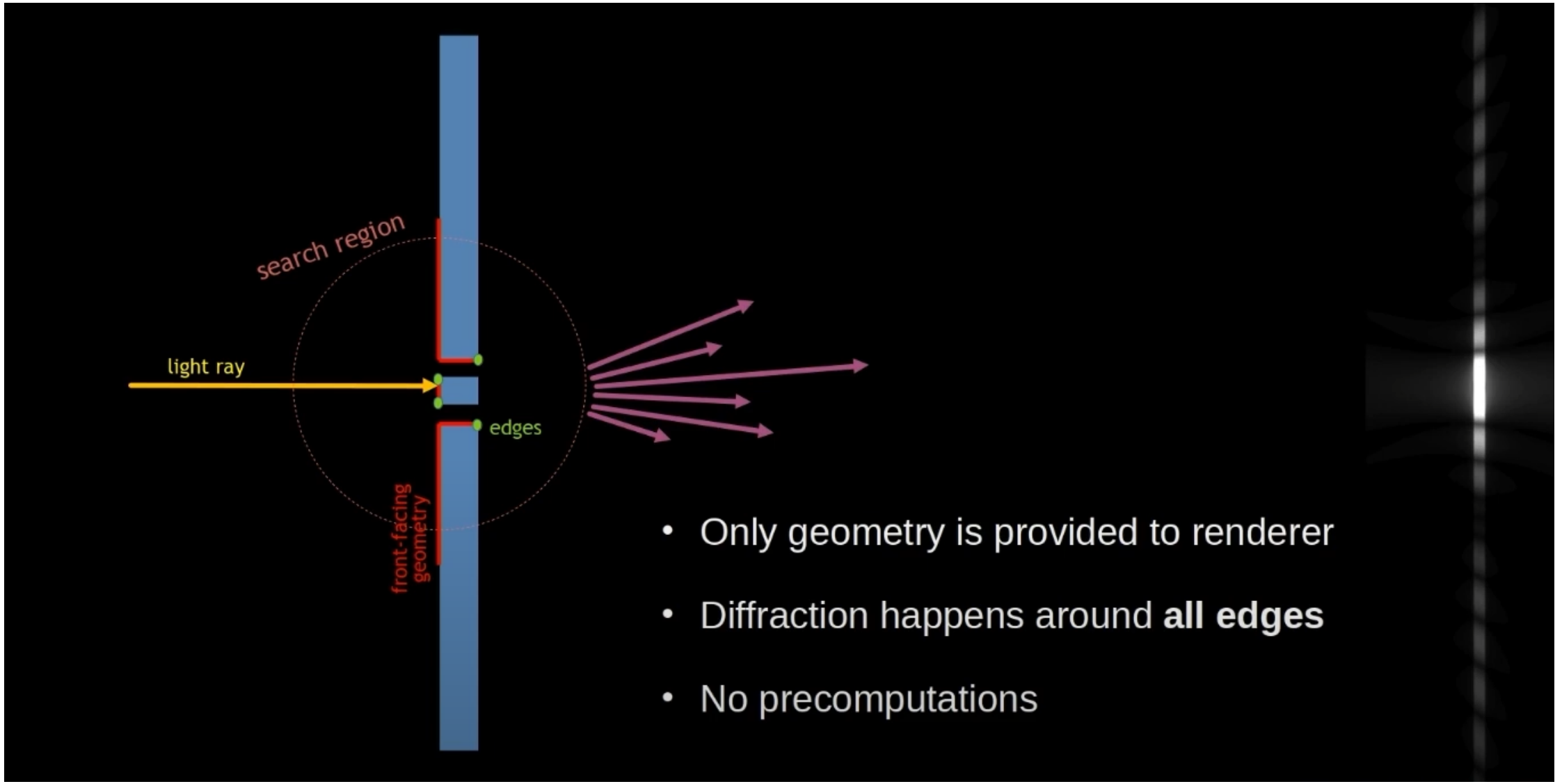
Methods



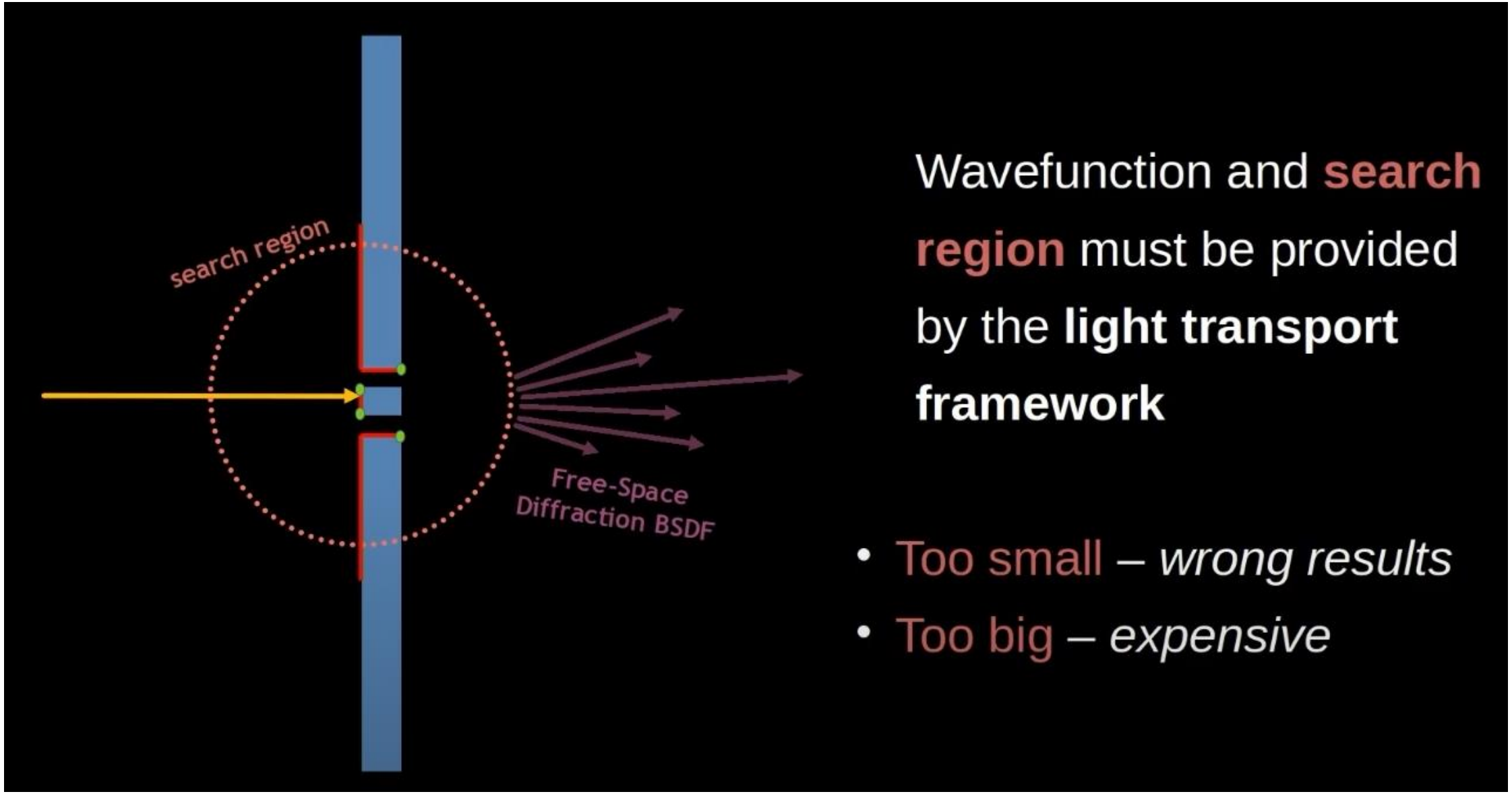
Methods


search region
light ray
new position
• Need to find a new position to continue tracing
• We rejection sample the aperture

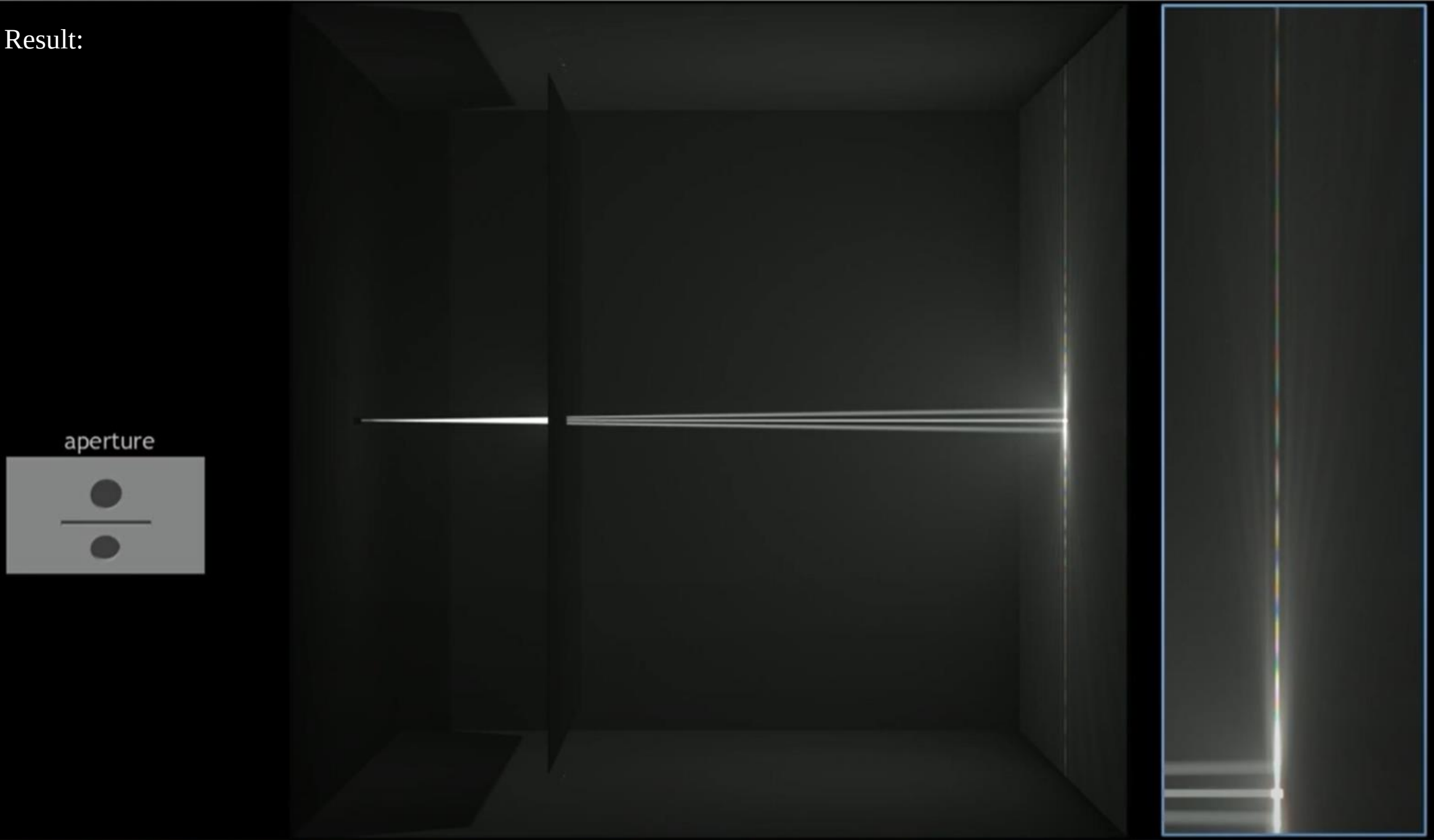
Methods


search region
light ray
edges
front-facing geometry
• Only geometry is provided to renderer
• Diffraction happens around **all edges**
• No precomputations

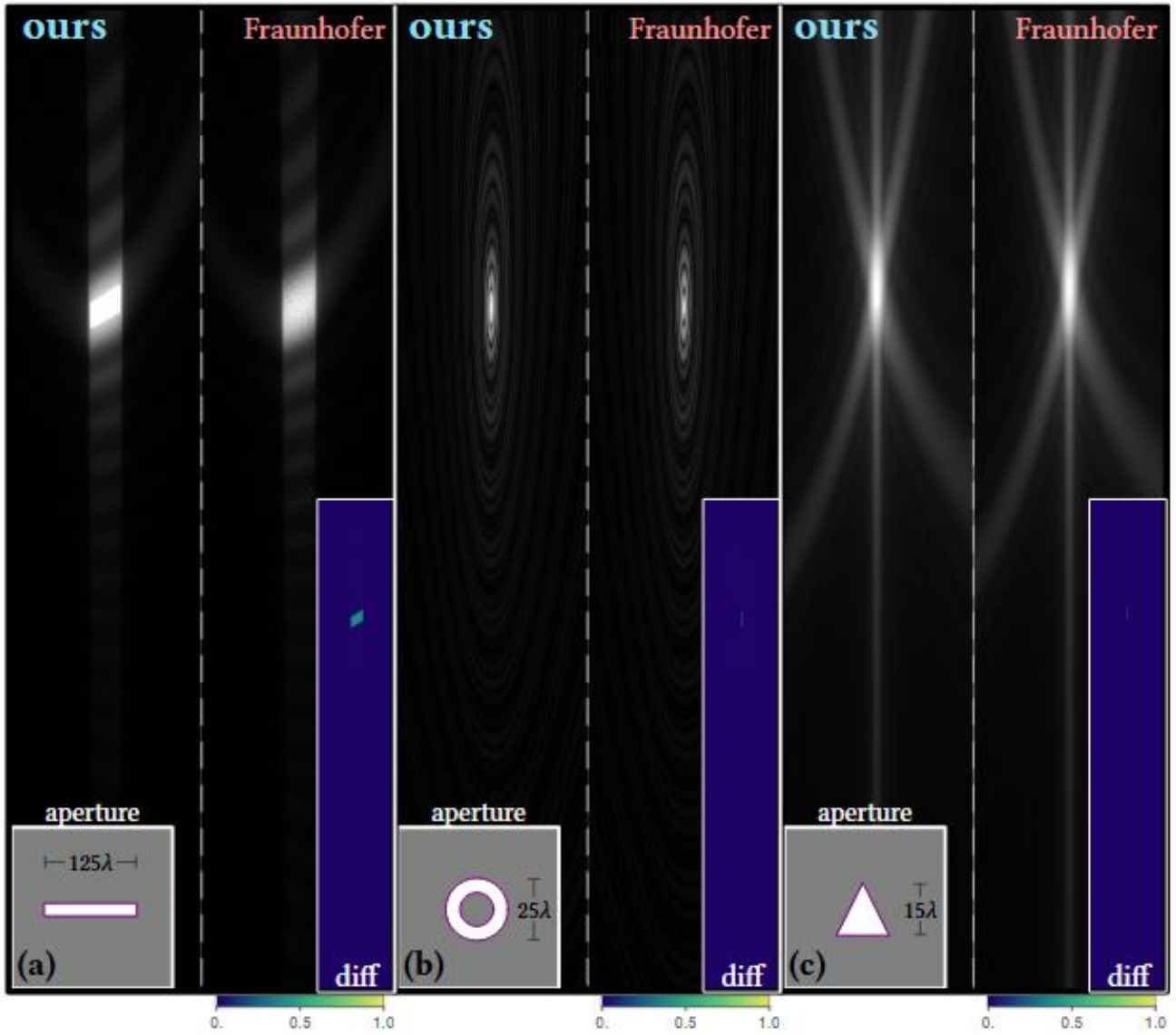
Methods


search region
Free-Space
Diffraction BSDF
Wavefunction and search region must be provided by the light transport framework
• Too small – wrong results
• Too big – expensive

Result:

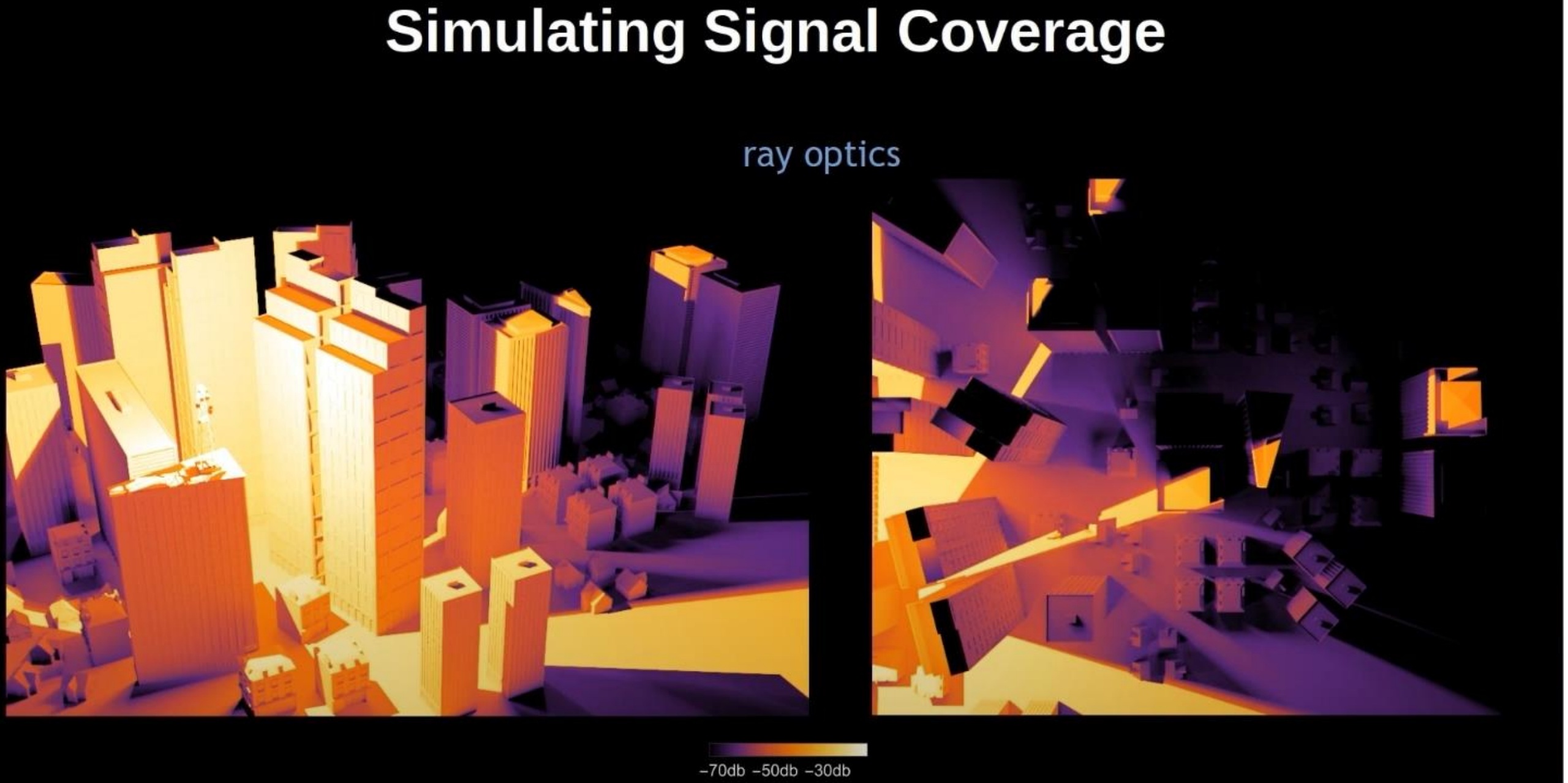


Result:

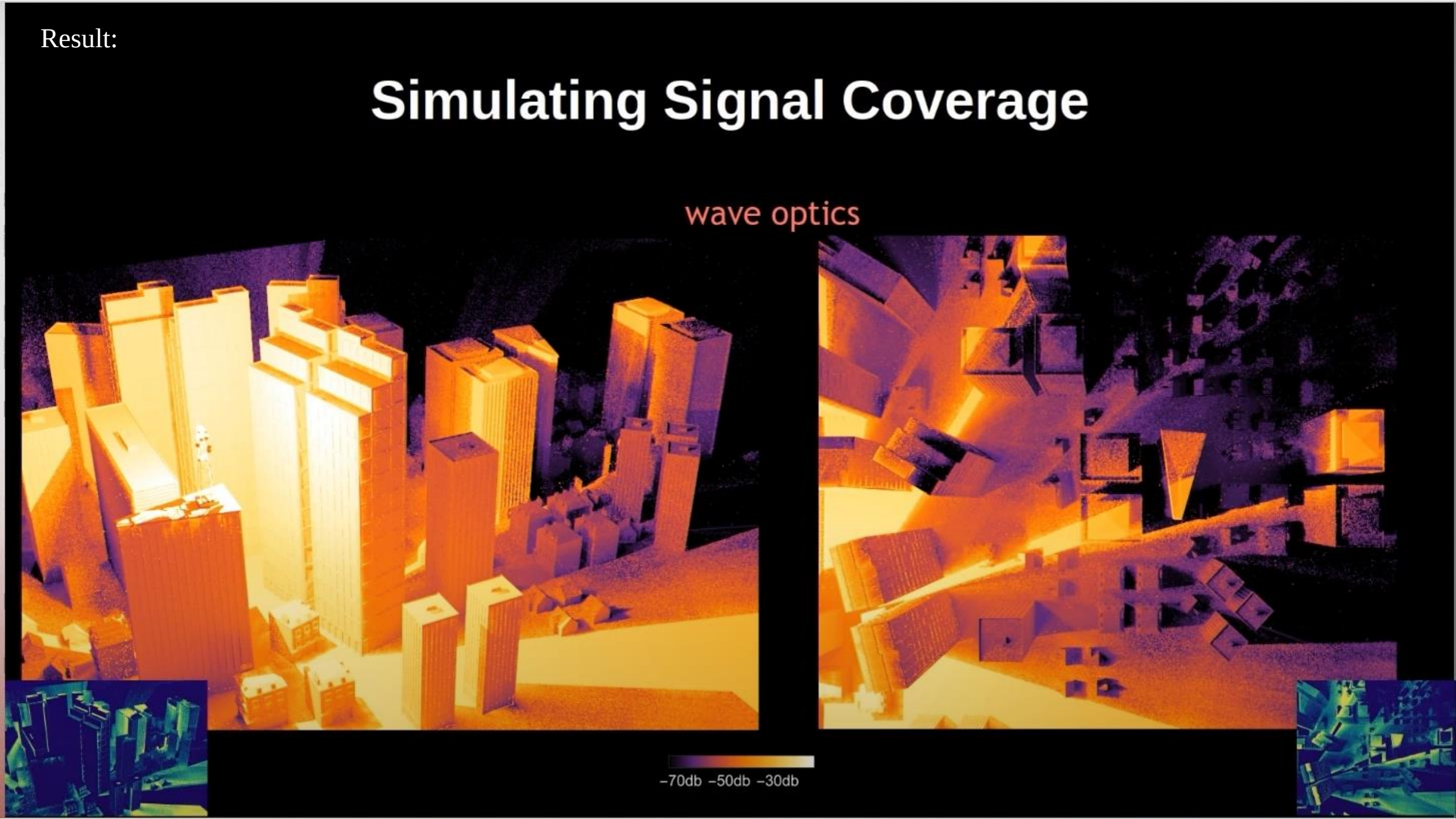


Validation against numerically-integrated Fraunhofer diffraction patterns

Result:



Result:



Summary and Limitations

- Designed to work with a **wave-optical light transport framework**
  - **A Generalized Ray Formulation For Wave-Optics Rendering,** 2023
  - **Towards Practical Physical-Optics Rendering,** 2022
  - **A Generic Framework for Physical Light Transport,** 2021

- Classical frameworks lack the information needed to diffract light

Summary and Limitations

Summary of Methods

1.Fraunhofer Diffraction and BSDF Construction:

A closed-form solution for Fraunhofer diffraction is derived, dynamically constructing BSDFs from triangular meshes.

2.Wave-Optical and Ray Tracing Integration:

The method integrates wave-optical effects into ray tracing using coherence-guided BSDF construction.

3.Efficient Sampling:

Importance sampling strategies are introduced to optimize computation in diffraction simulations.

Summary and Limitations

Limitations

1.Dependence on Acceleration Structures:

Triangle searches dominate computation time, limiting scalability.

2.Ad Hoc Search Regions:

Fixed search regions reduce accuracy in capturing diffraction effects precisely.

3.Bias in Energy Conservation:

Energy redistribution approximations may introduce small inaccuracies.

Future Directions

1.Optimization of Search and Sampling:

Improve efficiency in accessing triangles and sampling diffraction effects.

2.Wave-Optical Framework Integration:

Replace ad hoc regions with coherence-based limits for better accuracy.

3.Broader Applications:

Extend to acoustics and other wave phenomena simulations.

Quizs