Differentiable Ray Tracing Simulator

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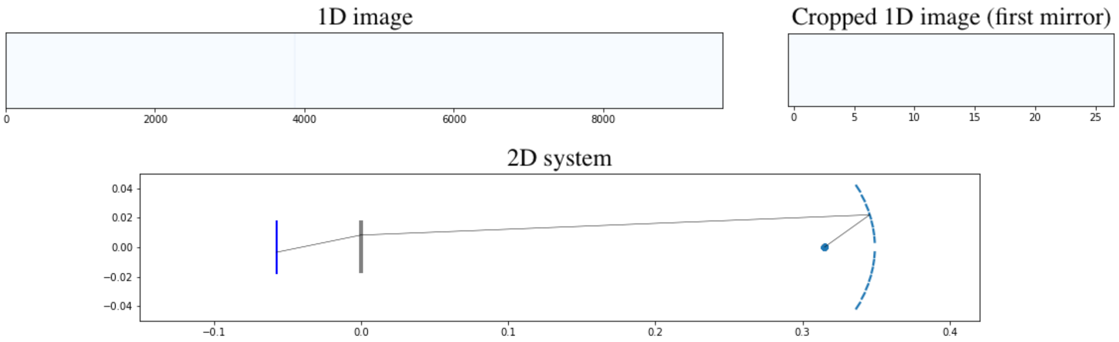
Plan

- Build a simulator of the MAGIS optical system.
- Insights:
  - Early insights about the system.
    - e.g. what is the impact of noise, quantum efficiency, …
  - Ability to test different systems.
    - e.g. different lenses, numerical apertures, …
- Inference:
  - High-fidelity model of the projection operator that can be used at inference time.
    - $\mathrm{A}(x) = b$.
  - End-to-end differentiable.

Approach

- Sample light rays from the atom cloud and model their interactions with the system (physically based rendering).



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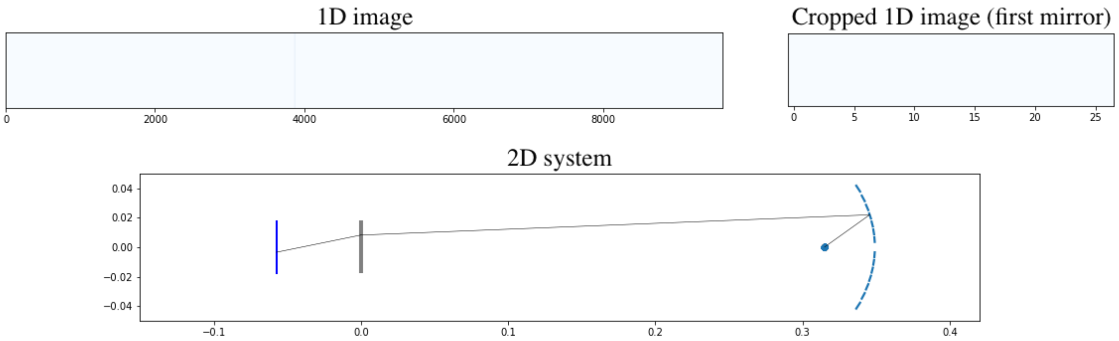
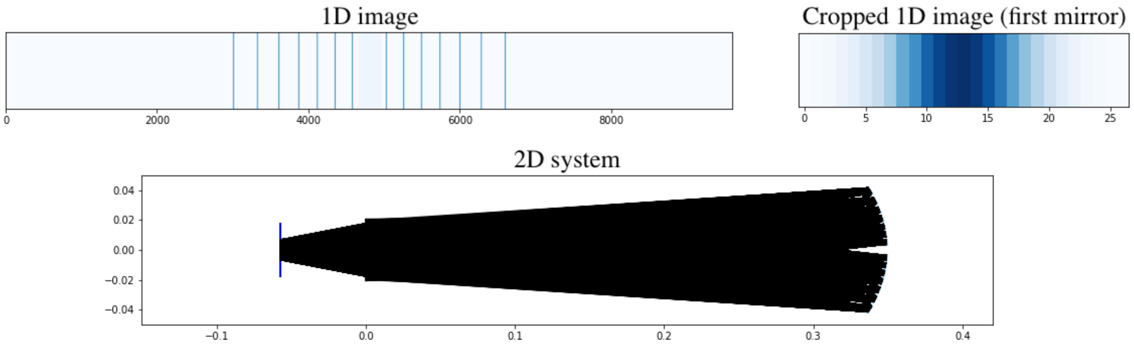




Next steps

1. Finish the extension of the simulator to 3D.
2. Complexify the system (noise, quantum efficiency, …).
3. 3D reconstruction & design of experiments.

Backup slides

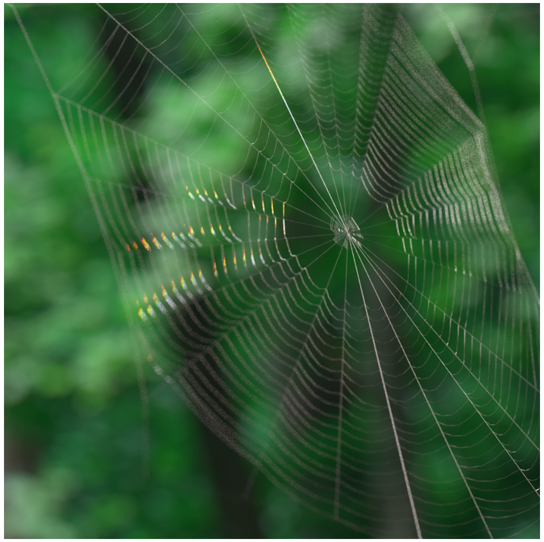
JAX

- Written in JAX (Autograd & XLA).
  - Autograd:
    - Automatically differentiates native Python and Numpy code.
    - Main purpose: gradient-based optimization.
  - XLA:
    - Compiles and runs programs on GPUs and TPUs (fused operations).
- Functional programming paradigm.
- Numpy (Python library) like syntax.
- Automatic parallelization & vectorization.

- Differentiability could also be used for design optimization.

Physically Based Rendering (1)

- Computer graphics approach that render images by modeling the behaviour of light rays in the real world.

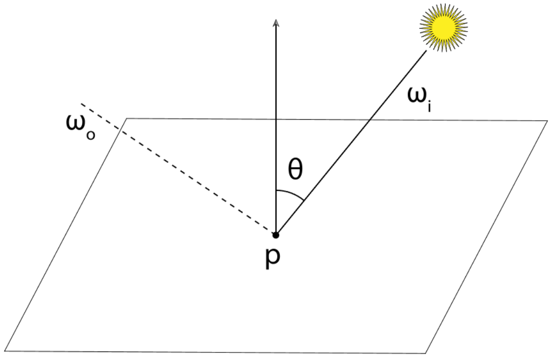


CS348B: Zach DeVito implemented a system for automatic spider web generation and then simulated wavelength dependent refraction through the web's threads.

Credits: https://graphics.stanford.edu/courses/cs348b-competition/cs348b-09/

Physically Based Rendering (2)

- Sample light rays from the camera and trace them until they hit a light source.
- Model the interaction of light rays with materials.
- Need to find which object in the scene a light ray will intersect first.
  - $\mathcal{O}(N)$ *where* N *is the number of objects in the scene.*
    - Not computational efficient.
      - Can be improved with exact or approximated algorithms.
    - We know exactly the setup.
      - Intersections can be computed in $\mathcal{O}(1)$.



Credits: *Physically Based Rendering: From Theory To Implementation.* Matt Pharr, Wenzel Jakob, and Greg Humphreys.