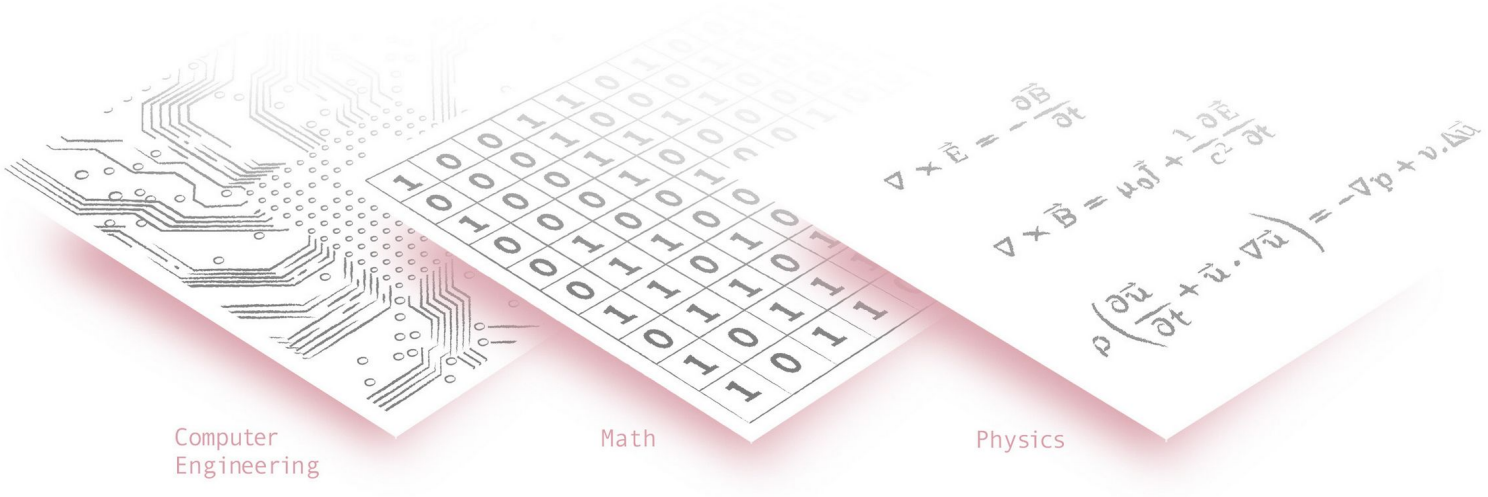


Inverse Design in Photonics

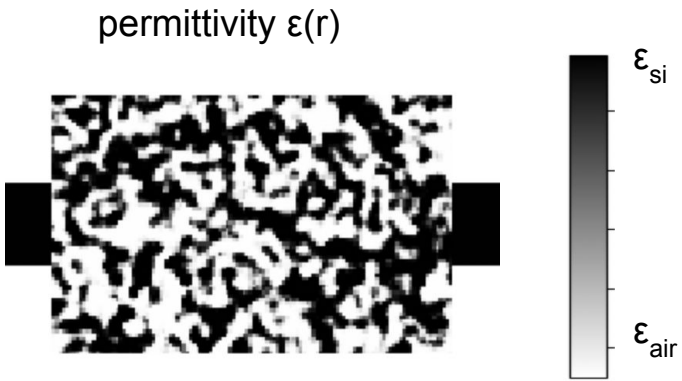
Tutorial 5: Shape Optimization

FLEXCOMPUTE

Tidy3D

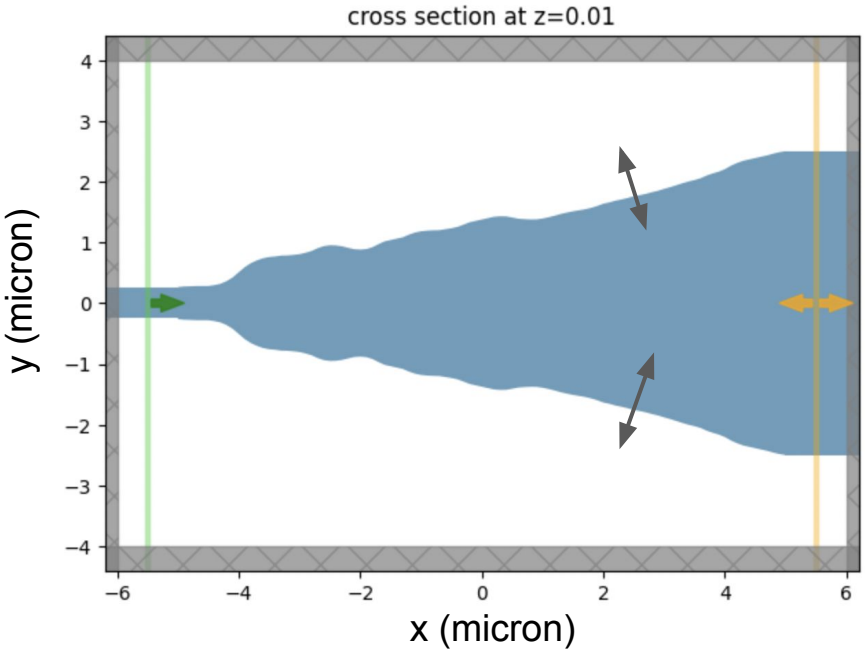
Review: Topology Optimization

- Previous model:
  - Break design region into independent pixels.
  - Optimize pixel permittivity value to meet objective.
  - Choose parameterization of pixels to satisfy fabrication constraints.
- While providing many degrees of freedom, for a class of waveguide problems, a shifting boundary approach would be sufficient.

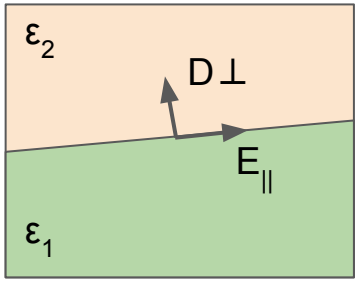


Another Approach: Shape Optimization

- Basic idea:
  - Parameterize the geometry of your device.
  - Optimize device geometry with respect to design variables.
- Advantages:
  - Choose parameterization to satisfy design criteria.
  - More intuitive designs.



Shifting Boundary Gradients



- Previously computed gradients w.r.t. permittivity within the volume of each pixel.
- Can derive an adjoint equation instead for a small shift in a boundary between two regions.

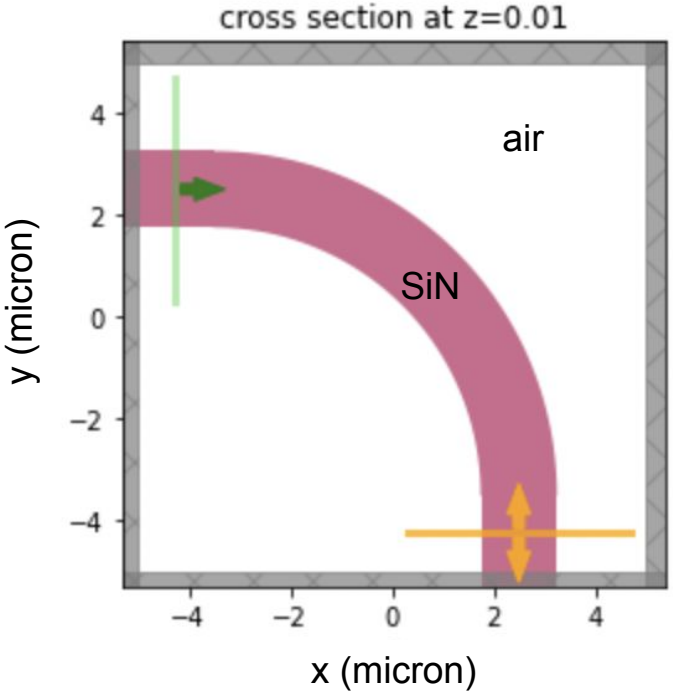
$$\frac{\partial T}{\partial s} = -k_0^2 \sum_i \Delta l_i^{-1} \frac{dh(\mathbf{r}_{\text{surf}i}, s)}{ds} [\Delta\epsilon_{12} \hat{E}_{\|i} E_{\|i} - \Delta(\epsilon_{12}^{-1}) \hat{D}_{\perp i} D_{\perp i}]$$

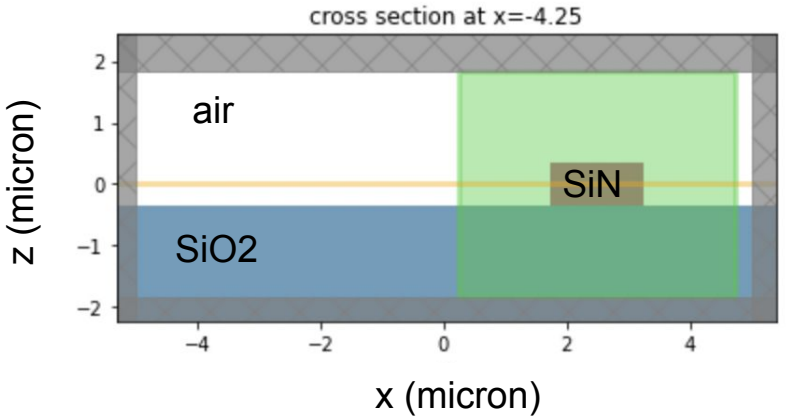
- Use this rule to compute gradients w.r.t. each geometric parameter using still only 2 simulations.

Veronis, Georgios, Robert W. Dutton, and Shanhui Fan. "Method for sensitivity analysis of photonic crystal devices." *Optics letters* 29.19 (2004): 2288-2290.

Example: 3D Waveguide Bend

- Optimize waveguide bend for maximum power transmission into fundamental mode.

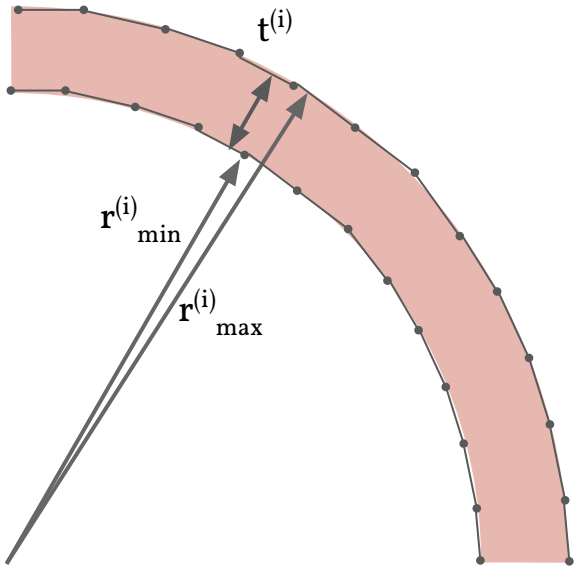




Tidy3D

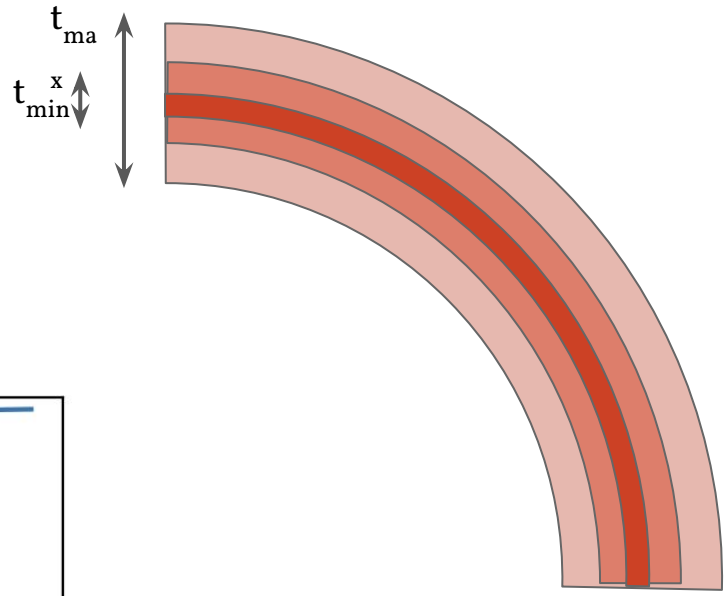
Shape Parameterization

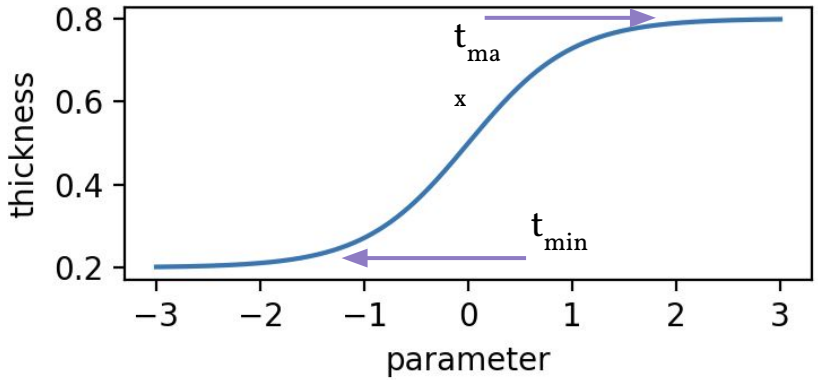
- Break circular bend into several sections.
- Parameter controls the thickness of each section.
- Define the bend as a polygon using these thicknesses.
- Optimize as before using shifting boundary gradient.



Thickness Bounds Constraint

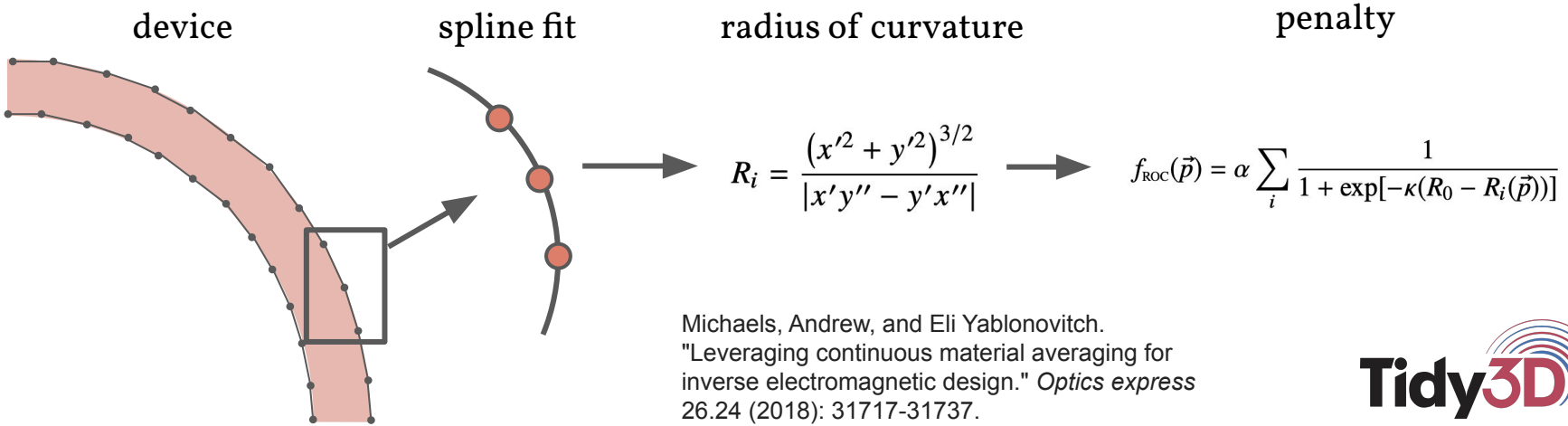
- Goal: Ensure that thickness each section is within range of values.
- Solution: Use tanh projection to map parameter to thickness within bounds.





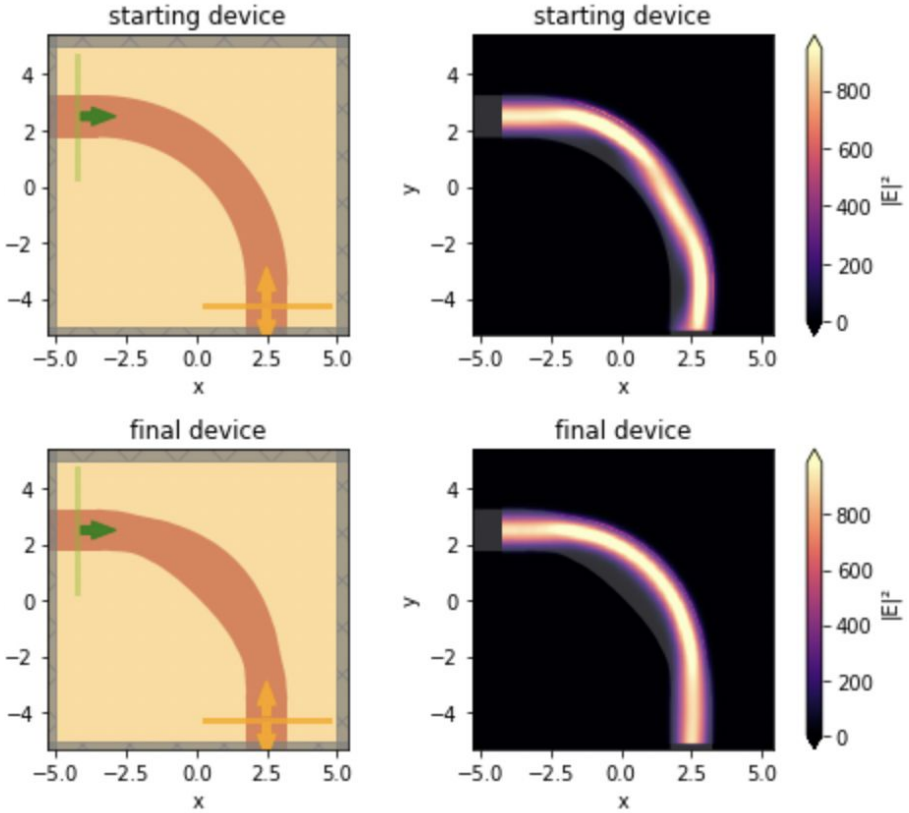
Radius of Curvature Penalty

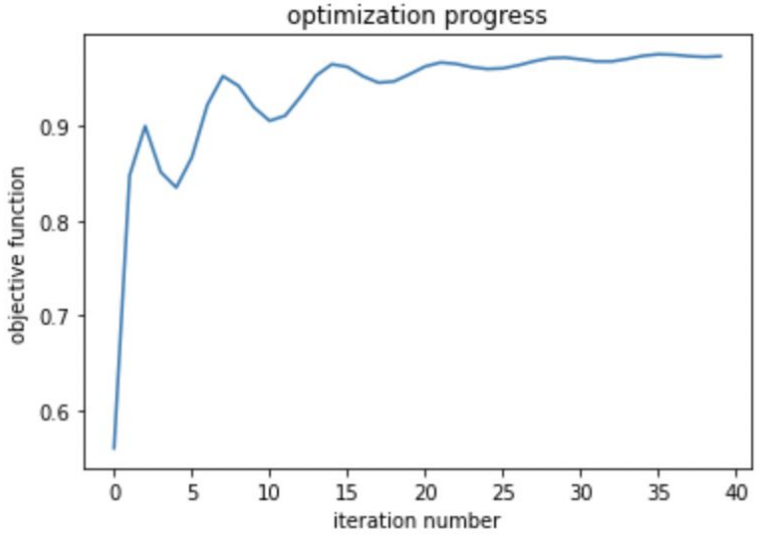
- Goal: Ensure that the thickness does not vary too widely along bend.
- Solution: Add penalty based on a fit of the radius of curvature.



Michaels, Andrew, and Eli Yablonovitch. "Leveraging continuous material averaging for inverse electromagnetic design." *Optics express* 26.24 (2018): 31717-31737.

Optimization Results





Summary

- Shape optimization is often an effective alternative to topology optimization (pixels).
- Need to pick a parameterization that works with your system.
- Add some fabrication penalties as needed.