Session 5

Inverse Design in Photonics

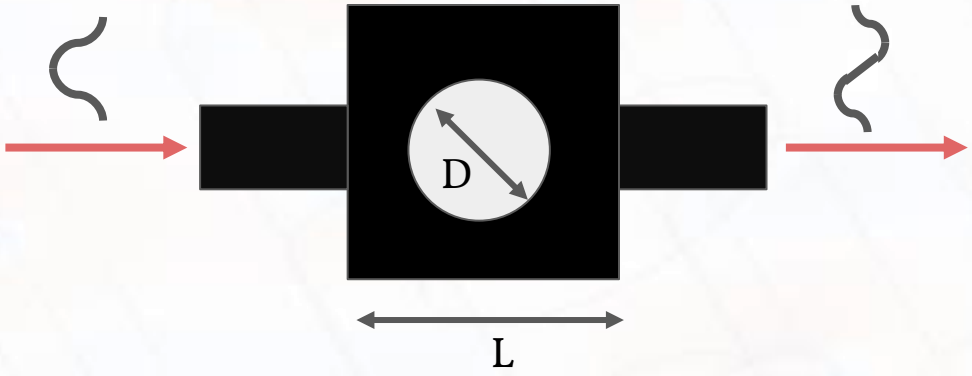
Automating device design through optimization

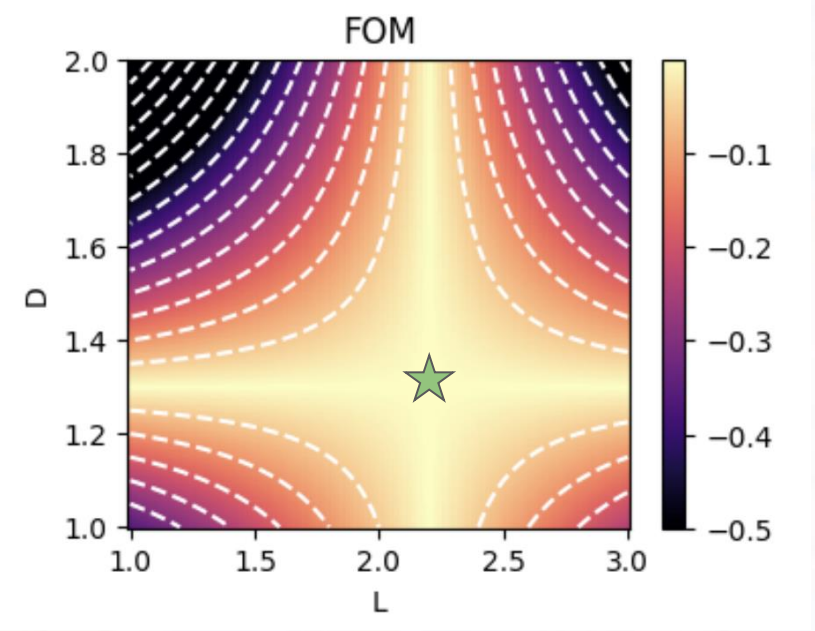
Dr. Tyler W Hughes
Principal Research Scientist
Ph.D. Stanford

March 8, 2024 • 1PM CST

Device Design in Photonics

Goal: convert from fundamental to higher order mode.





Tune / sample parameters “L”, “D”.
Pick best result.

Design as Mathematical Optimization

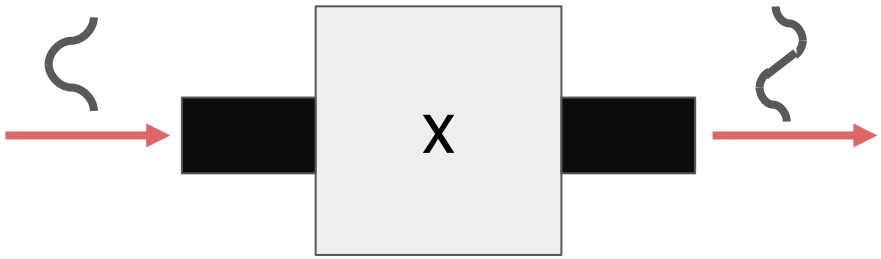
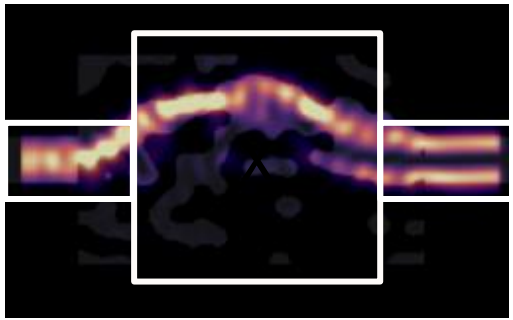


Figure of merit Design parameters constraints

$$\underset{x}{\text{minimize}} \quad f_0(x)$$

$$\text{subject to} \quad f_i(x) \leq b_i$$

Field intensity



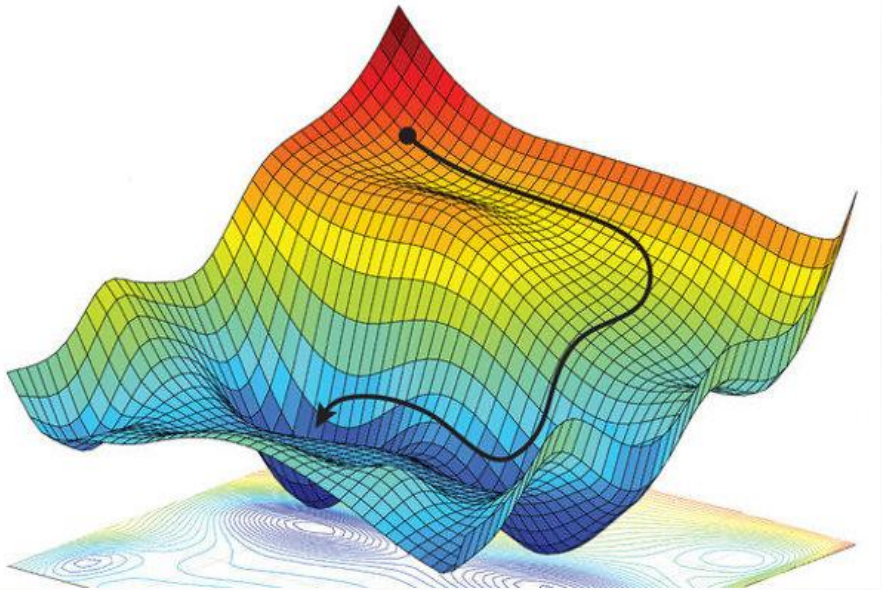
Final design



Gradient-Based Optimization

$$\underset{x}{\text{minimize}} \quad f_0(x)$$

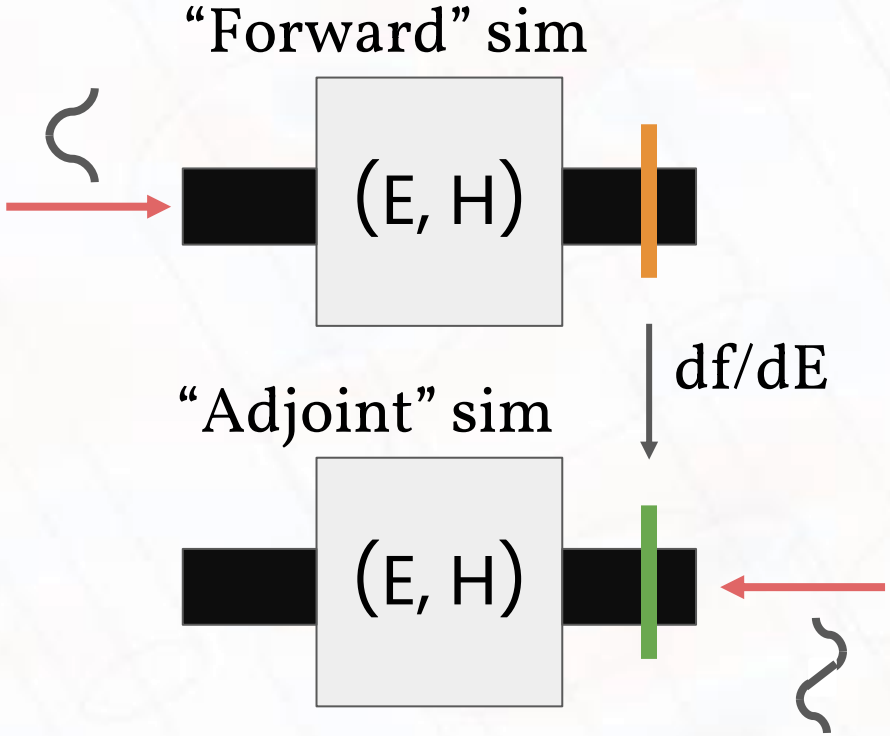
A simple approach that works



while not optimized :

$$x_i := x_i - \alpha \frac{df_0}{dx_i} \longleftarrow \text{gradient } \nabla_x f$$

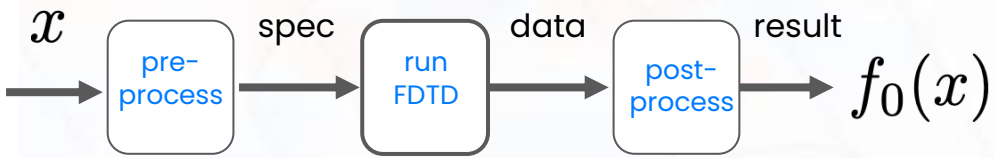
Adjoint Method



- Run original sim, measure fields.
- Adjoint simulation encodes loss information in sources.
- Run adjoint sim, measure fields.
- Overlap integrals of fields.
- Full gradient, just 2 simulations!

Hughes, Tyler W., et al. ACS Photonics 5.12 (2018): 4781-4787.

Automatic Differentiation in Tidy3D



$$\nabla_x f \leftarrow J_{ij} \leftarrow \boxed{J_{ij}} \leftarrow J_{ij} \leftarrow \partial f_0$$

- Derivative of complicated pipeline is just multiplication of derivatives of each step.
- We write a generalized Jacobian for Tidy3D simulations and let JAX handle the rest.

```python
def f0(x: np.ndarray) -> float:
  """Objective Function"""
  sim = preprocess(x)
  data = tidy3d.web.run(sim)
  return postprocess(data)

# just evaluate f0(x)
value = f0(x0)

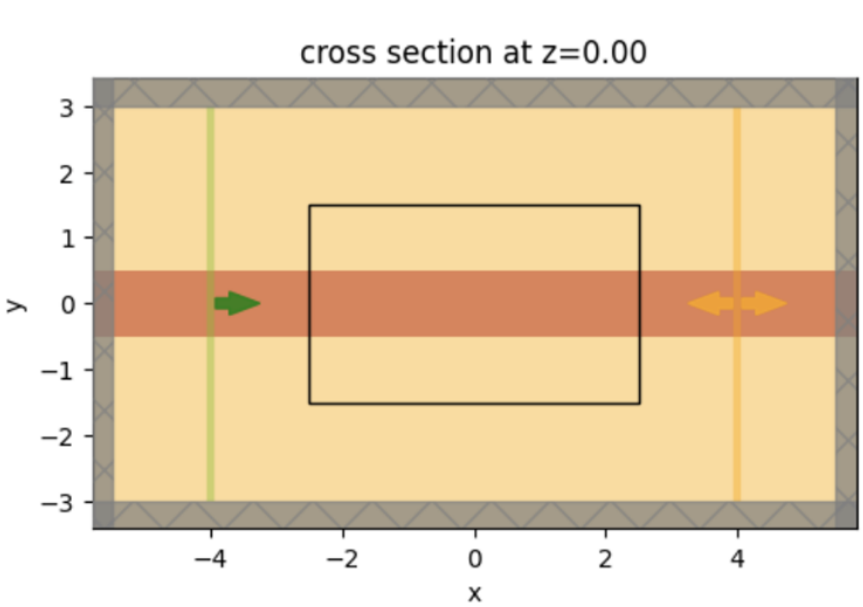
# construct the gradient fn
grad_fn = jax.grad(f0)

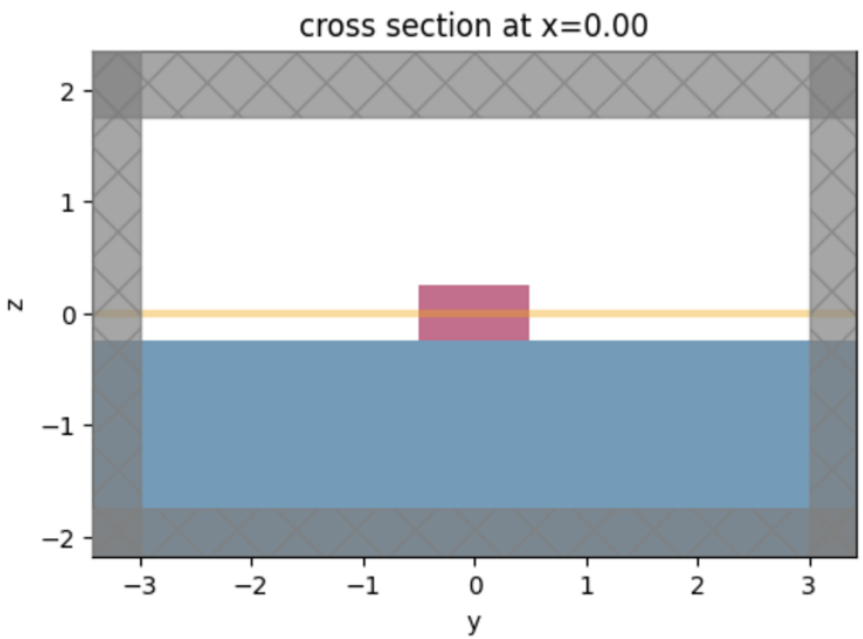
# evaluate the gradient
grad_value = grad_fn(x0)
```

https://jax.readthedocs.io/en/latest/

Today's Demo

Inverse design the mode converter in Tidy3D.

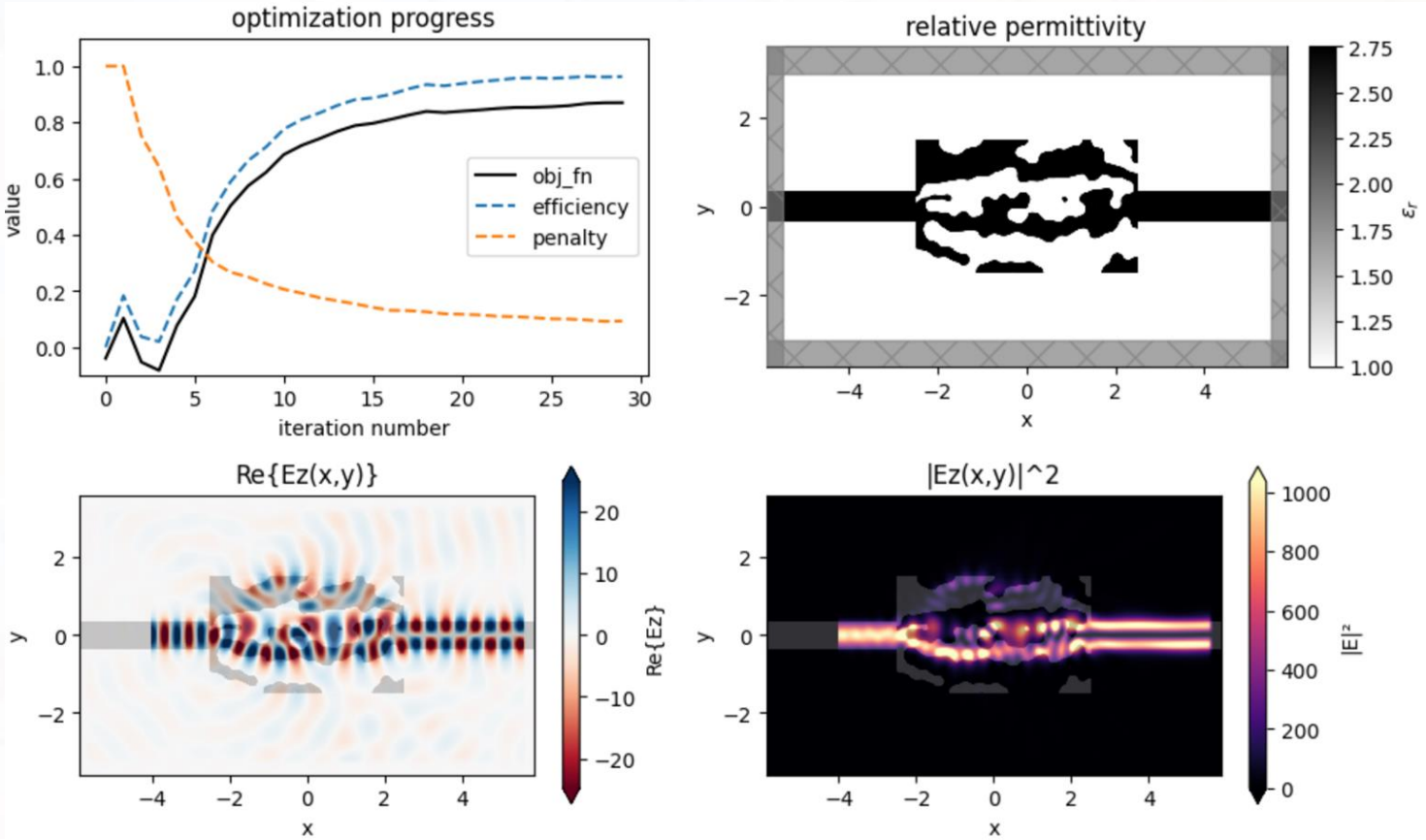




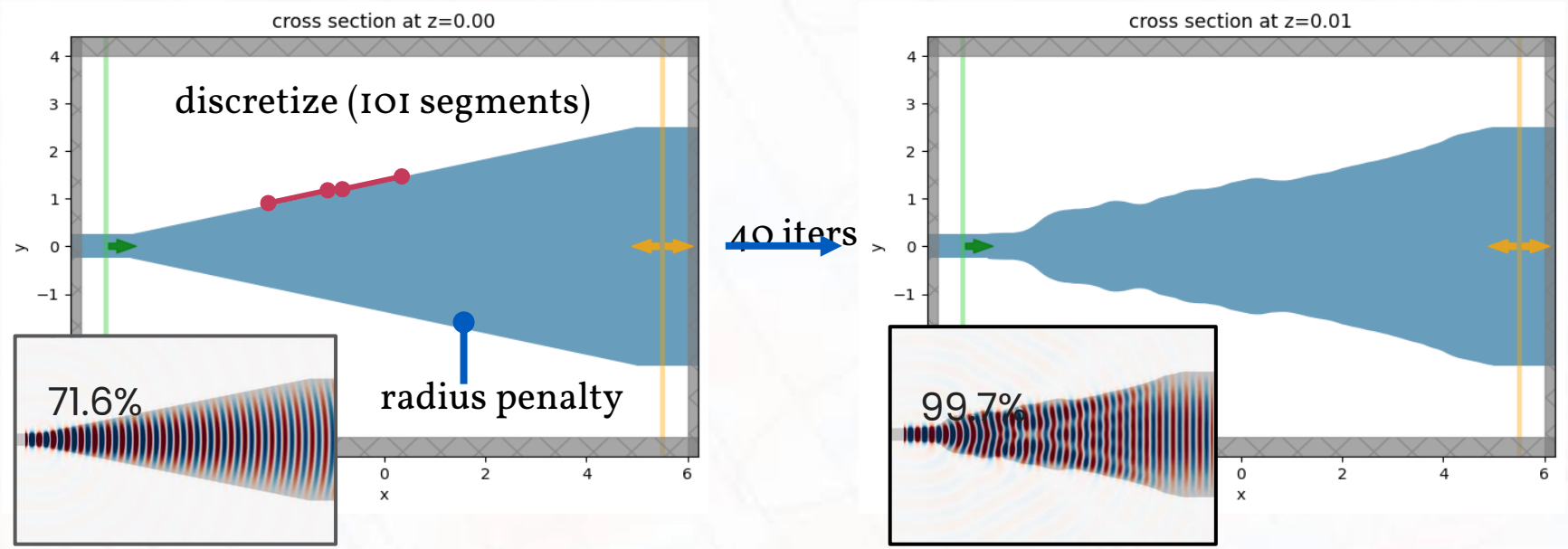
Hands-on activity

Inverse Design of Integrated Photonic Mode Converter

Notebook Result

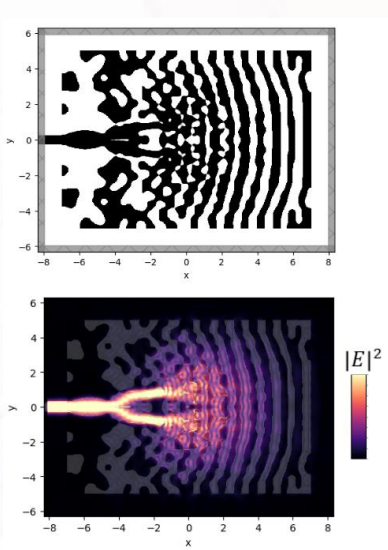


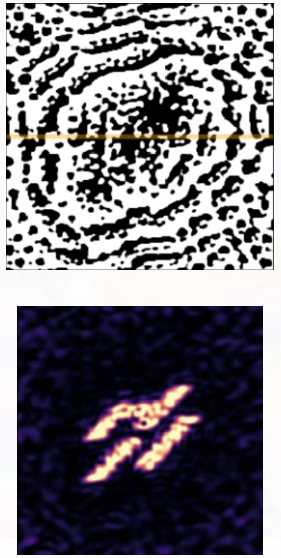
Shape Optimization

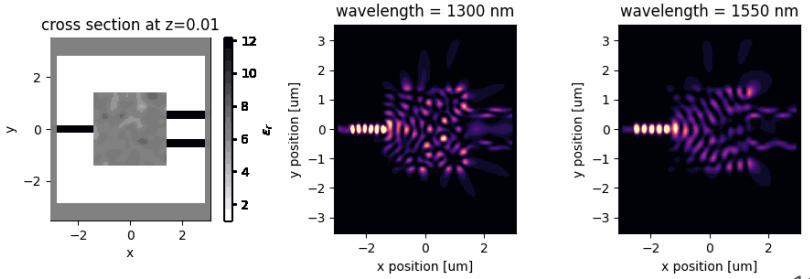


Extensions of Inverse Design

- Modal amplitudes.
- Flux through a plane.
- Arbitrary field / intensity pattern.
- Diffraction amplitudes.
- Embedded circuit simulation.
- Multi-frequency.
- And many others…







https://docs.flexcompute.com/projects/tidy3d/en/latest/notebooks/docs/features/adjoint.html

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The FDTD Method

Feb 9 Dr. Weiliang Jin • *Princeton, Stanford*



Multimode Photonics Design

Feb 16 Dr. Lucas Gabrielli • *Cornell*



Designing Filters + Reflectors

Feb 23 Dr. Tom Chen • *Stony Brook*



Photonic Crystal Slabs

Mar 1 Dr. Momchil Minkov • *EPFL, Stanford*



Inverse Design in Photonics

Mar 8 Dr. Tyler Hughes • *Stanford*

Tidy3D

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