

GENERATIVE  
RENAISSANCE

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ASIA 2025  
HONG KONG 港

Conference 15 – 18 December 2025

Exhibition 16 – 18 December 2025

Venue Hong Kong Convention  
and Exhibition Centre

**Automated design of  
compound lenses with  
discrete-continuous  
optimization**

Arjun Teh, Delio Vicini, Bernd Bickel,  
Matthew O'Toole, Ioannis Gkioulekas

Carnegie Mellon University and Google

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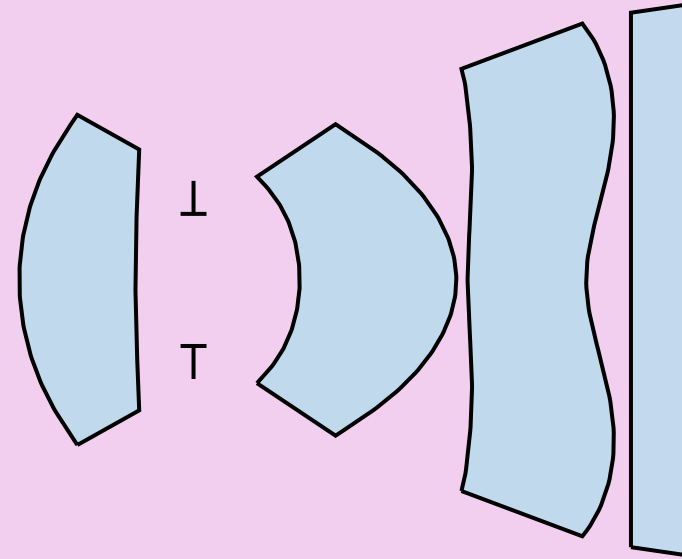
# Lenses are everywhere



# Many kinds of designs

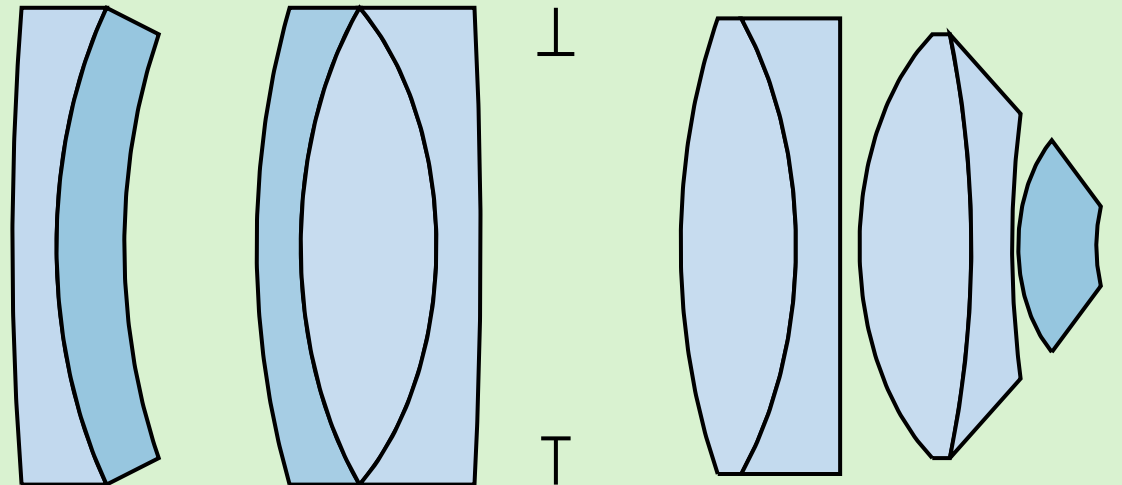
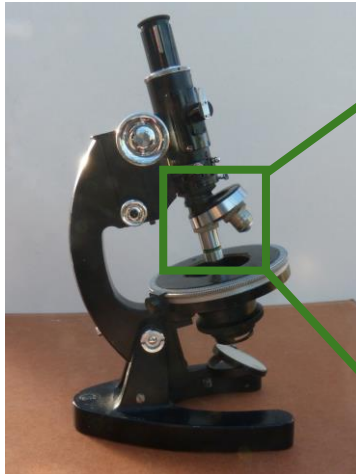
wide angle

fast



high resolution

no aberrations

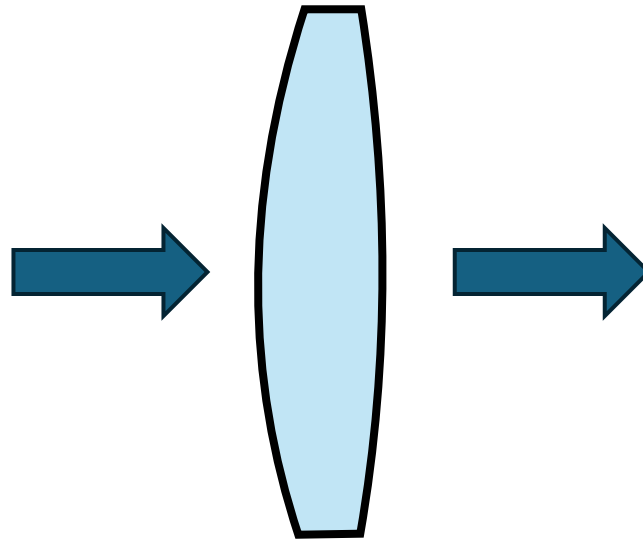




# Simple lenses aren't enough



scene



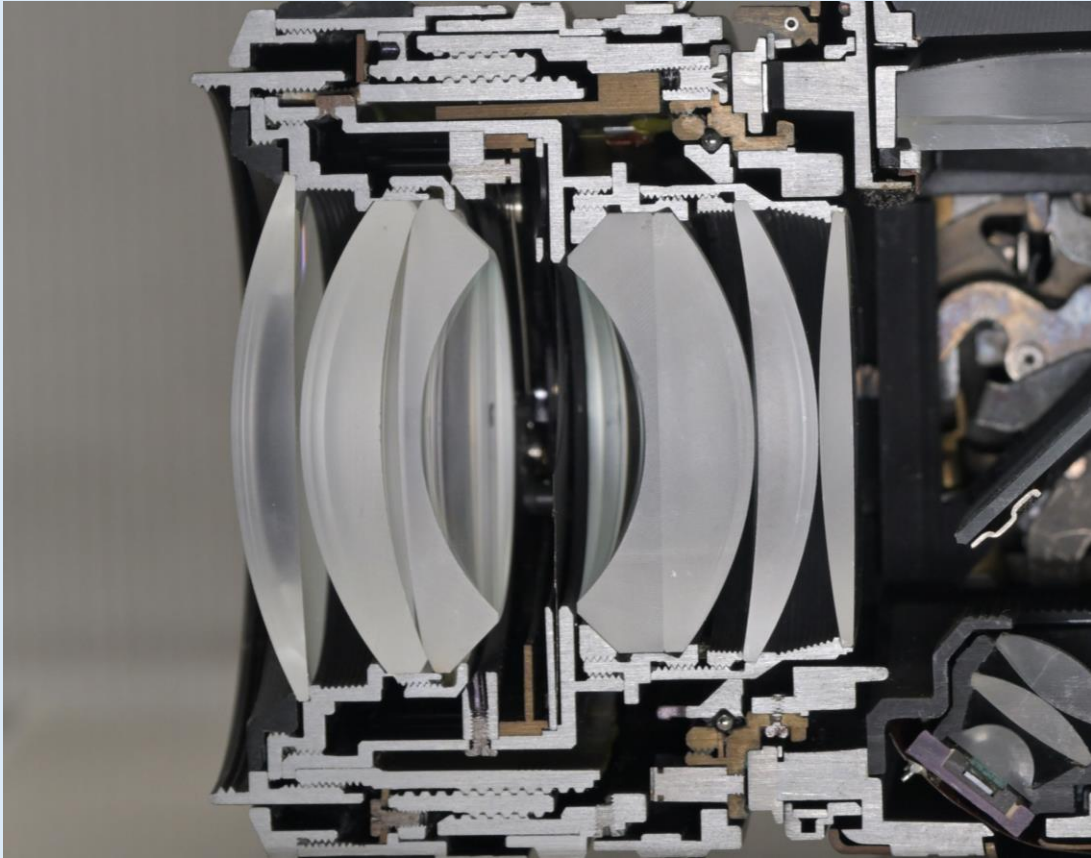
singlet lens



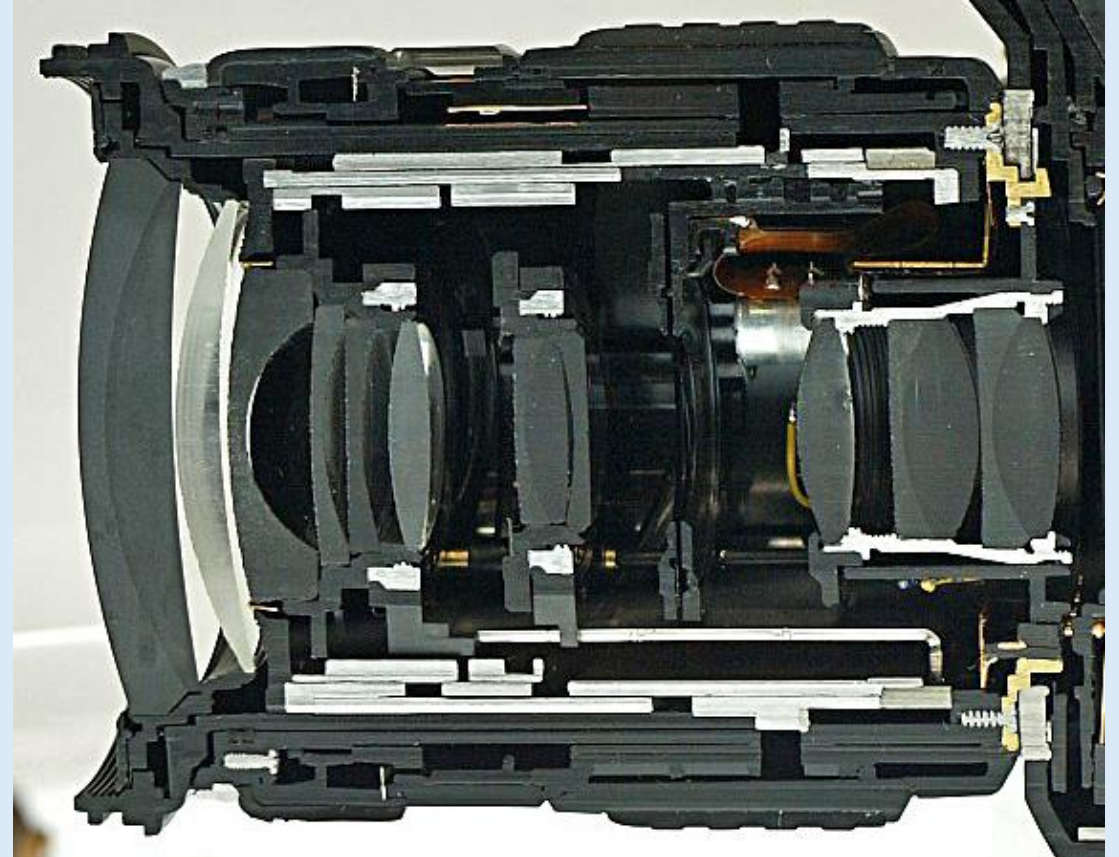
result

# Modern lenses are complicated

Nikon F3 Cutaway



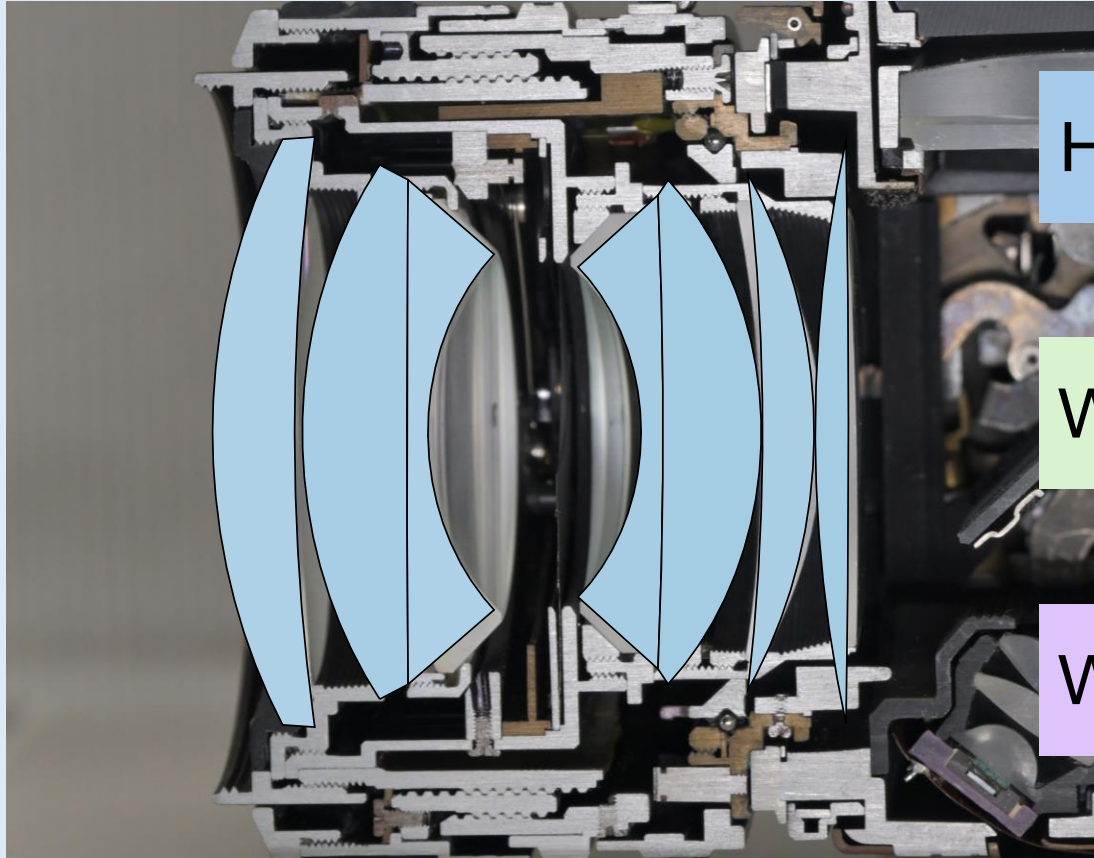
Olympus E-30 Cutaway





# Combinatorially many discrete options

Nikon F3 Cutaway

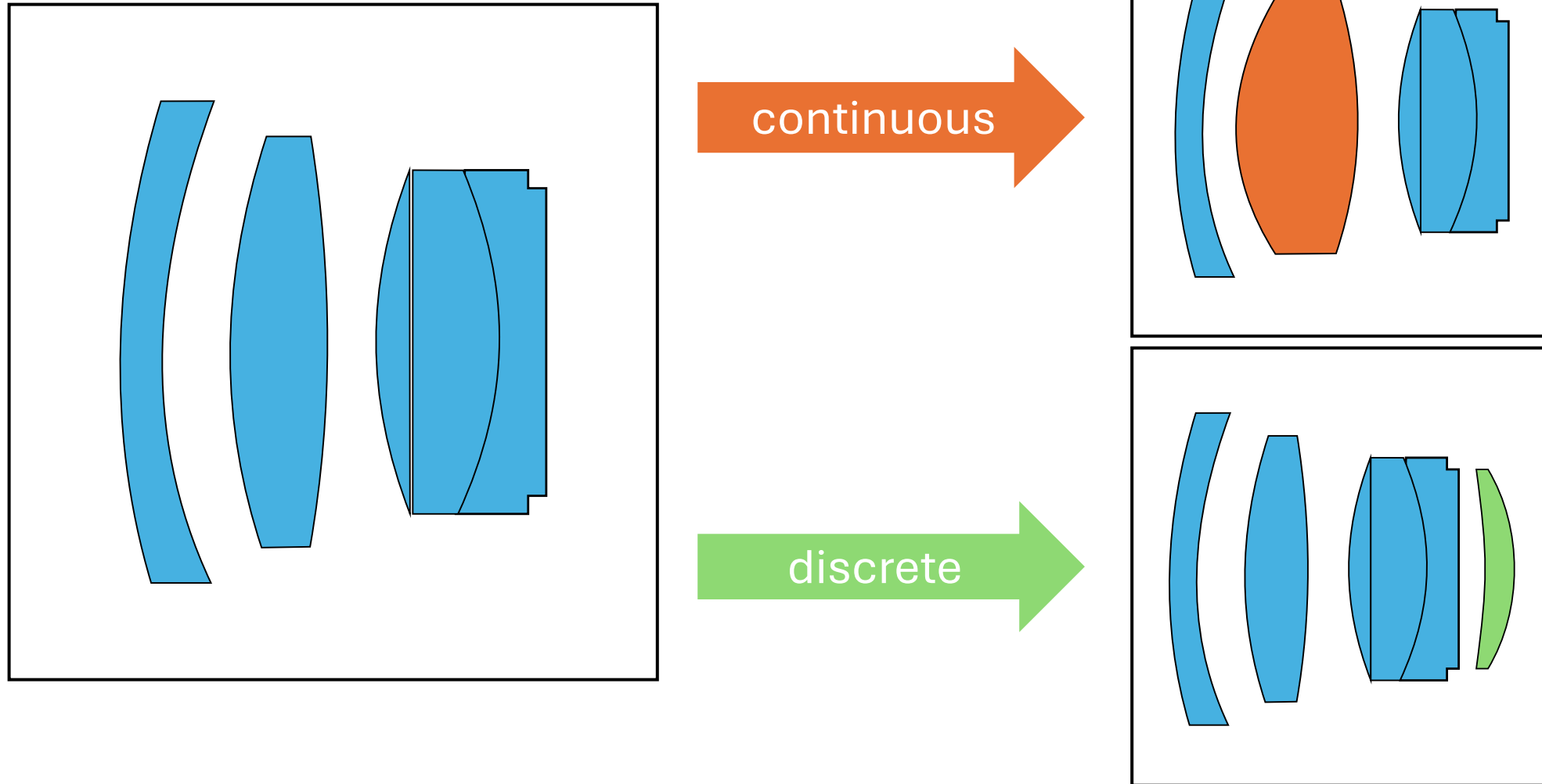


How many elements?

Which elements are glued together?

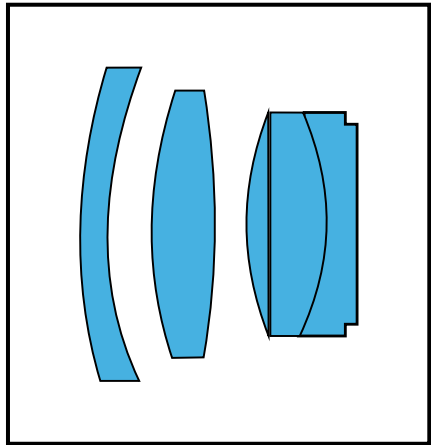
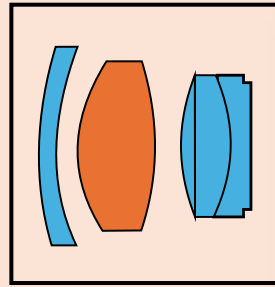
What order and orientation?

# Two types of parameters

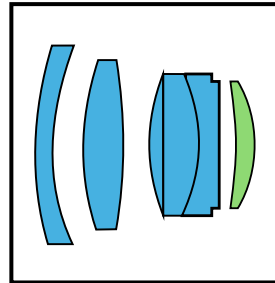


# Two types of parameters

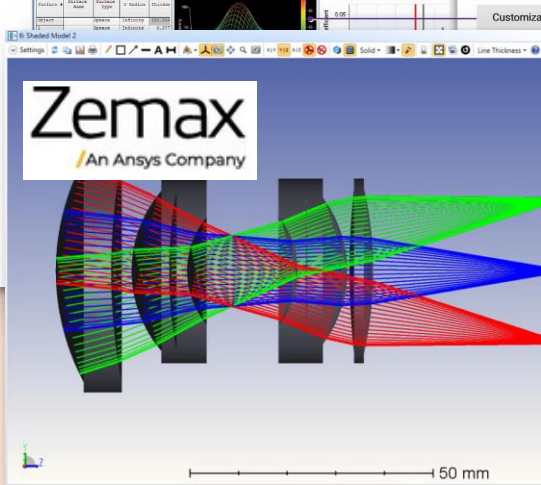
continuous



discrete



CODE V Optical Design Software  
Design, Optimize and Fabricate Reliable  
Imaging Optics



dO: A differentiable engine for Deep Lens design  
of computational imaging systems

Congli Wang, Ni Chen, and Wolfgang Heidrich, *Fellow, IEEE*

Abstract—Computational imaging systems algorithmically or data-driven machine learning, are applied to raw images and

Aperture-Aware Lens Design

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## ABSTRACT

Optics designers use simulation tools to assist them in designing lenses for various applications. Commercial tools rely on finite differencing and sampling methods to perform gradient-based optimization of lens design objectives. Recently, differentiable rendering techniques have enabled more efficient gradient calculation of these objectives. However, these techniques are unable to optimize for light throughput, often an important metric for many applications.

We develop a method for calculating the gradients of optical systems with respect to both focus and light throughput. We formulate lens performance as an integral loss over a dynamic domain, which allows for the use of differentiable rendering techniques to calculate the required gradients. We also develop a ray tracer specifically designed for refractive lenses and derive formulas for calculating gradients that simultaneously optimize for focus and light throughput. Explicitly optimizing for light throughput produces lenses that outperform traditional optimized lenses that tend to prioritize for only focus. To evaluate our lens designs, we simulate various applications where our lenses: (1) improve imaging performance in low-light environments, (2) reduce motion blur for high-speed photography, and (3) minimize vignetting for large-format sensors.

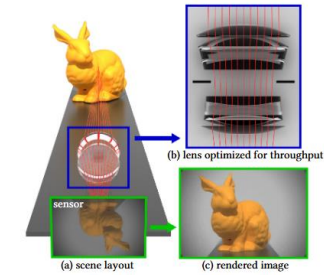
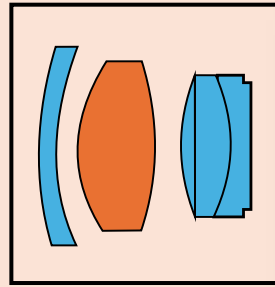


Figure 1: (a) The objective of this work is to design lenses capa-



# Two types of parameters

continuous



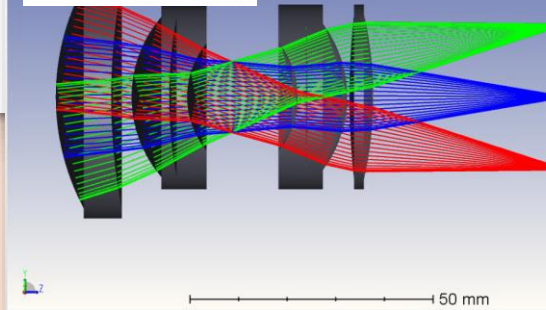
## CODE V Optical Design Software

Design, Optimize and Fabricate Reliable Imaging Optics



## Zemax

An Ansys Company



## dO: A differentiable engine for Deep Lens design of computational imaging systems

Congli Wang, Ni Chen, and Wolfgang Heidrich, *Fellow, IEEE*

**Abstract**—Computational imaging systems algorithmically or data-driven machine learning, are applied to raw images and

## Aperture-Aware Lens Design

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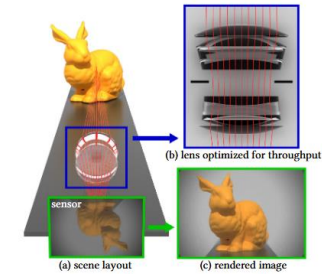
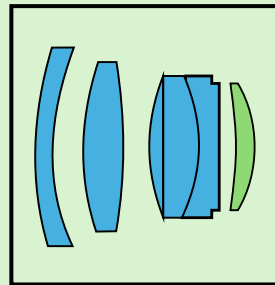


Figure 1: (a) The objective of this work is to design lenses capa-

discrete



## Genetic algorithms for lens design: a review

Kaspar Hoeschel<sup>1</sup> • Vasudevan Lakshminarayanan<sup>2</sup>

Received: 6 July 2018 / Accepted: 27 November 2018 / Published online: 6 December 2018  
© The Author(s) 2018

**Abstract** Genetic algorithms (GAs) have a long history of over four decades. GAs are adaptive heuristic search algorithms that provide solutions for optimization and search problems. The GA derives expression from the biological terminology of natural selection, crossover, and mutation. In fact, GAs simulate the processes of natural evolution. Due to their unique simplicity, GAs are applied to the search space to find optimal solutions for various problems in science and engineering. Using GAs for lens

surface profile types such as spherical, aspheric, diff or holographic. Usually, the design space for optic tems consists of multi-dimensional parameter Moreover, the radius of curvature, distance to th surface, material type and optionally tilt, and decen necessary for lens design [2].

The most important aspects for designing optical are optical performance or image quality, manufac and environmental requisitions. *Optical performa*

## LensNet: lens design starting point generator

### Get started

Enter the effective focal length, f-number and half field of view desired for your lens design project. Our deep learning framework will infer a selection of lens designs tailored to those specifications.

Focal length (in mm)  
25.0

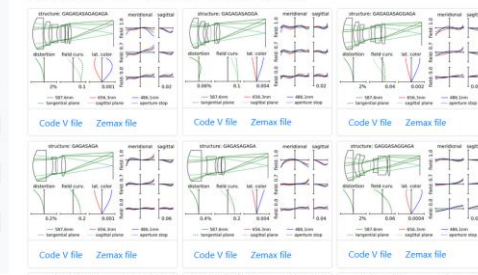
F-number  
3.0

Half field of view (in degrees)  
12.0

Submit

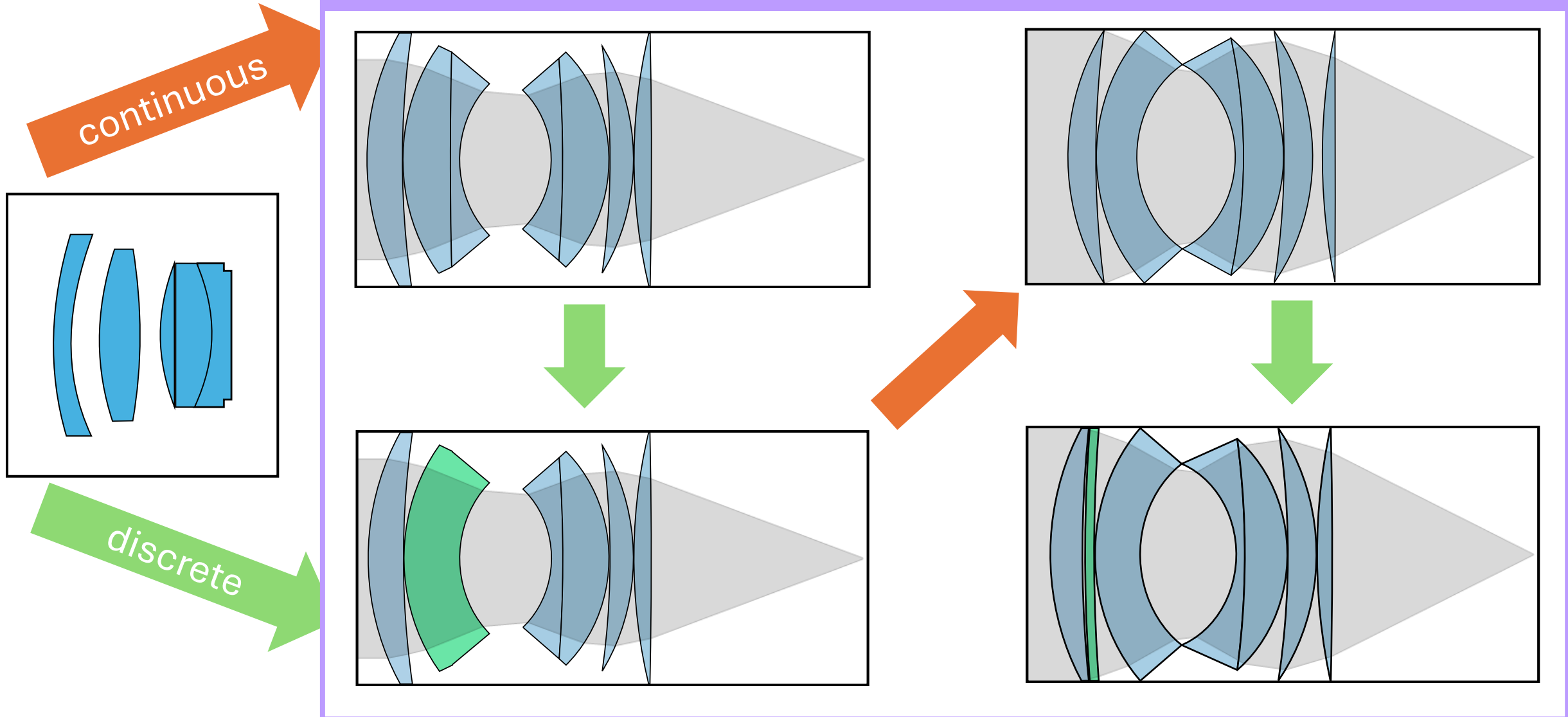
### Results

focal length: 25.0 mm, f-number: 3.0, half field of view: 12.0°



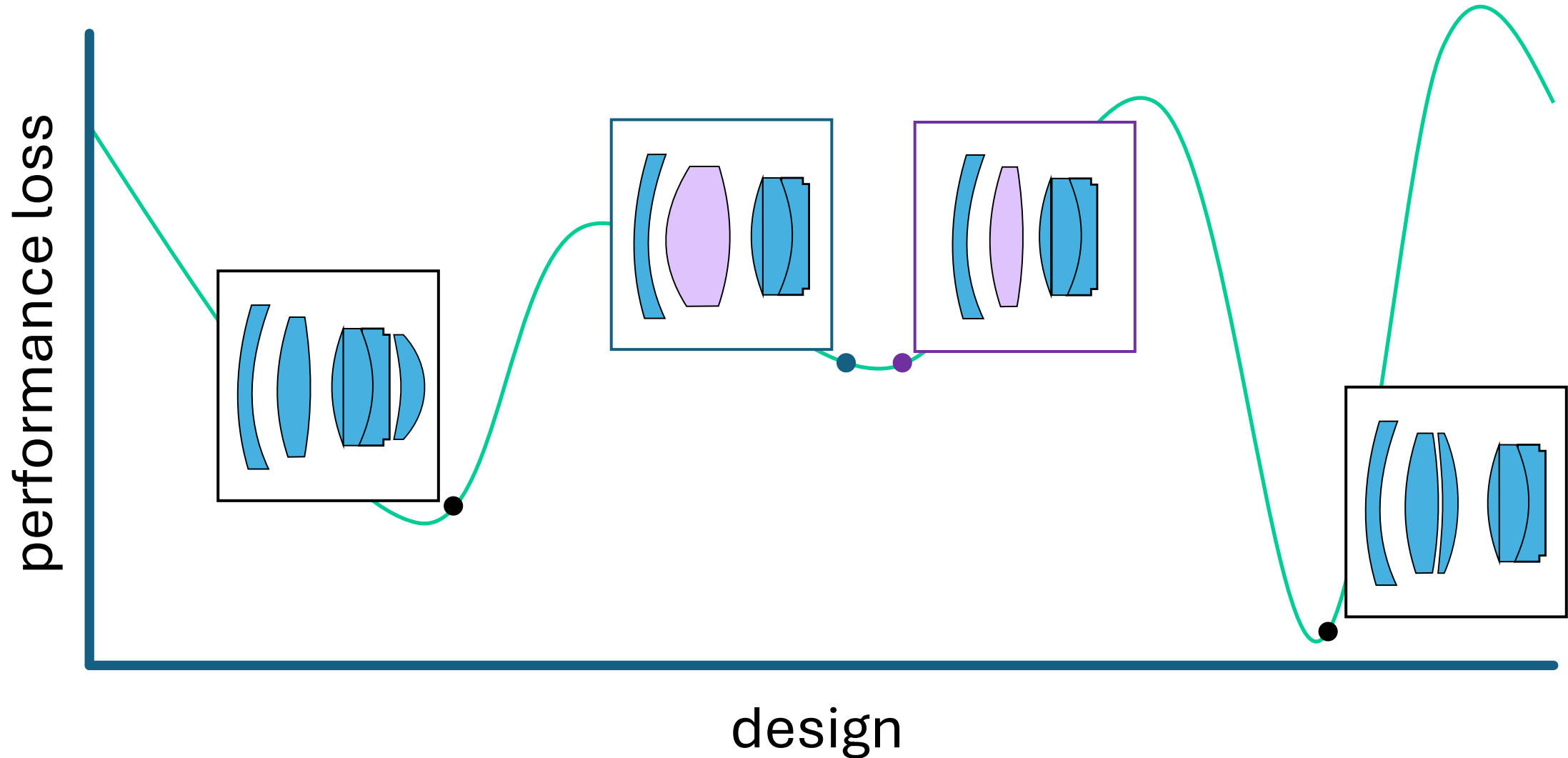
# Two types of parameters

## Mixed discrete-continuous optimization

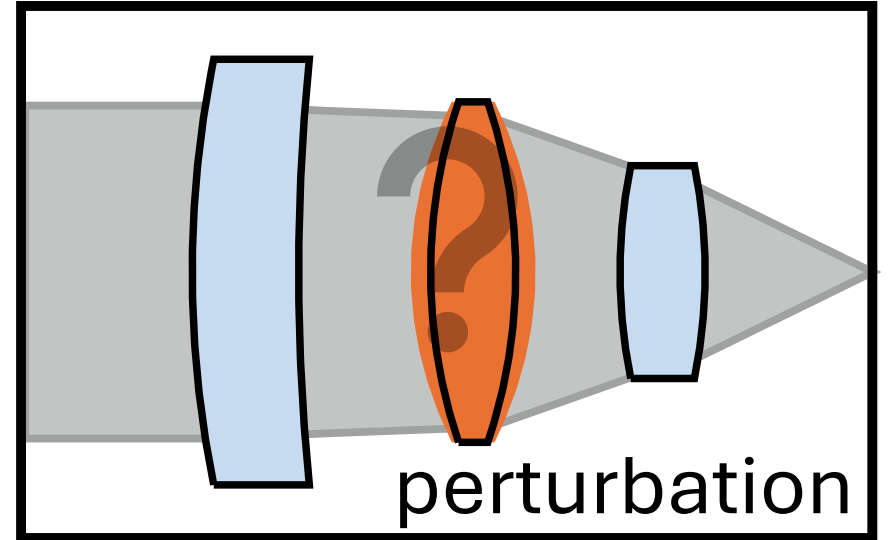
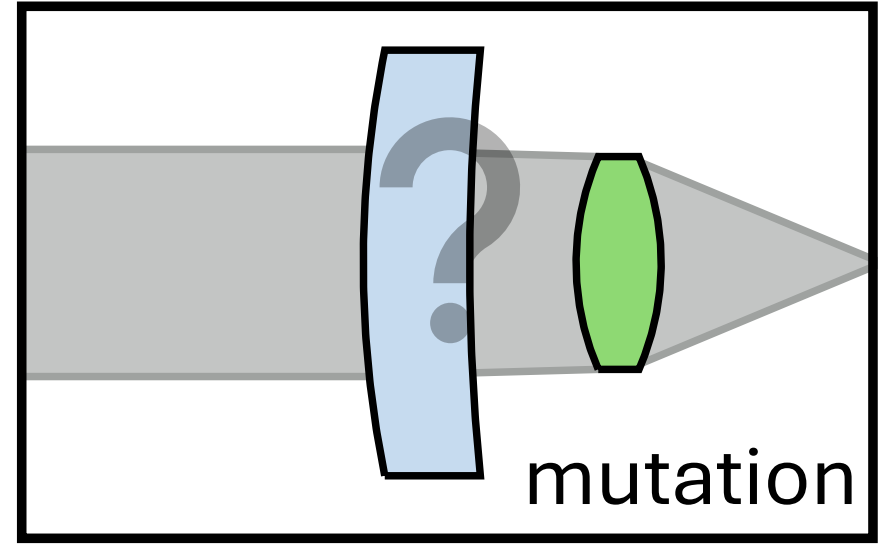
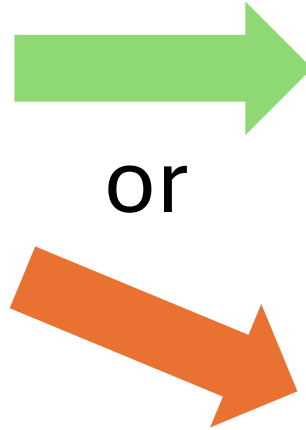
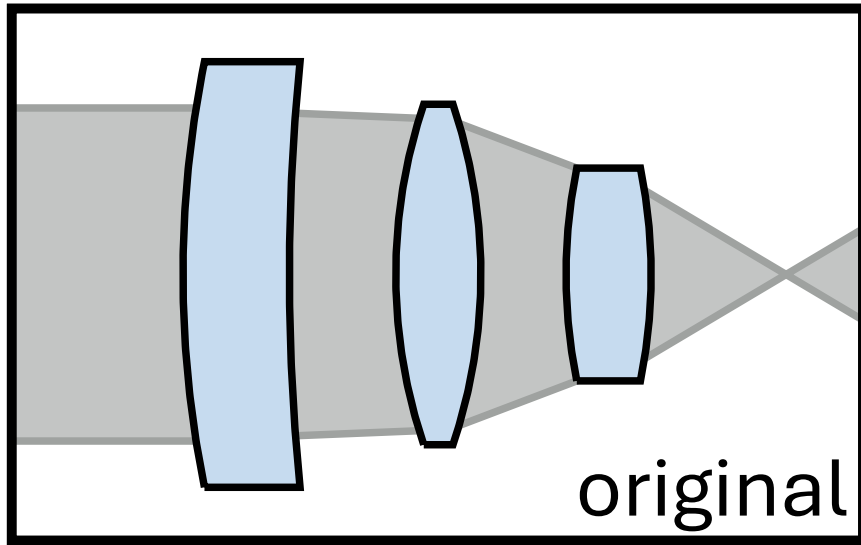




# Key idea: sample the space of designs

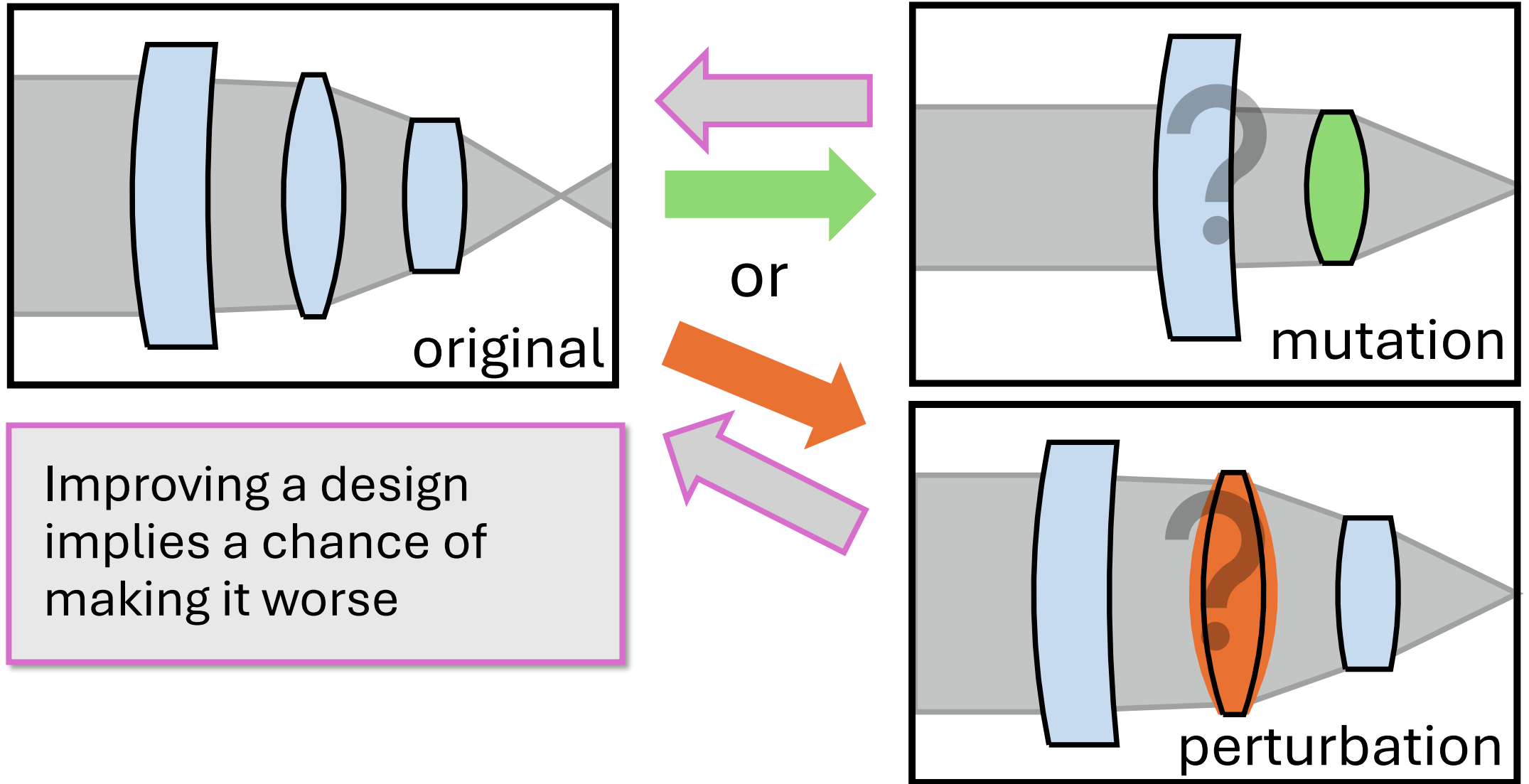


# Metropolis-Hastings



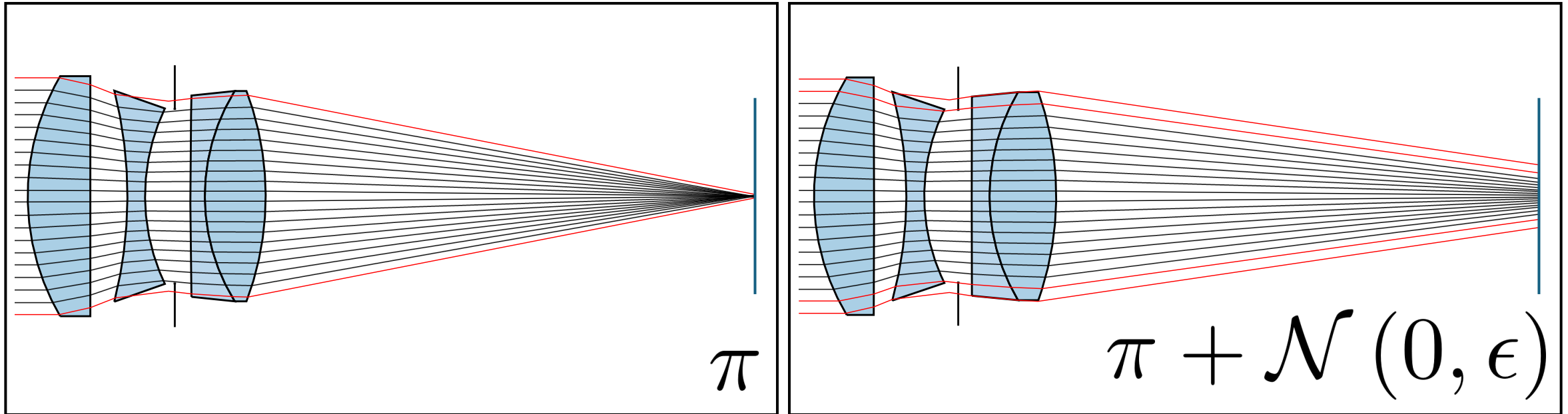


# Metropolis-Hastings requires reversibility



# Metropolis-Hastings requires noise

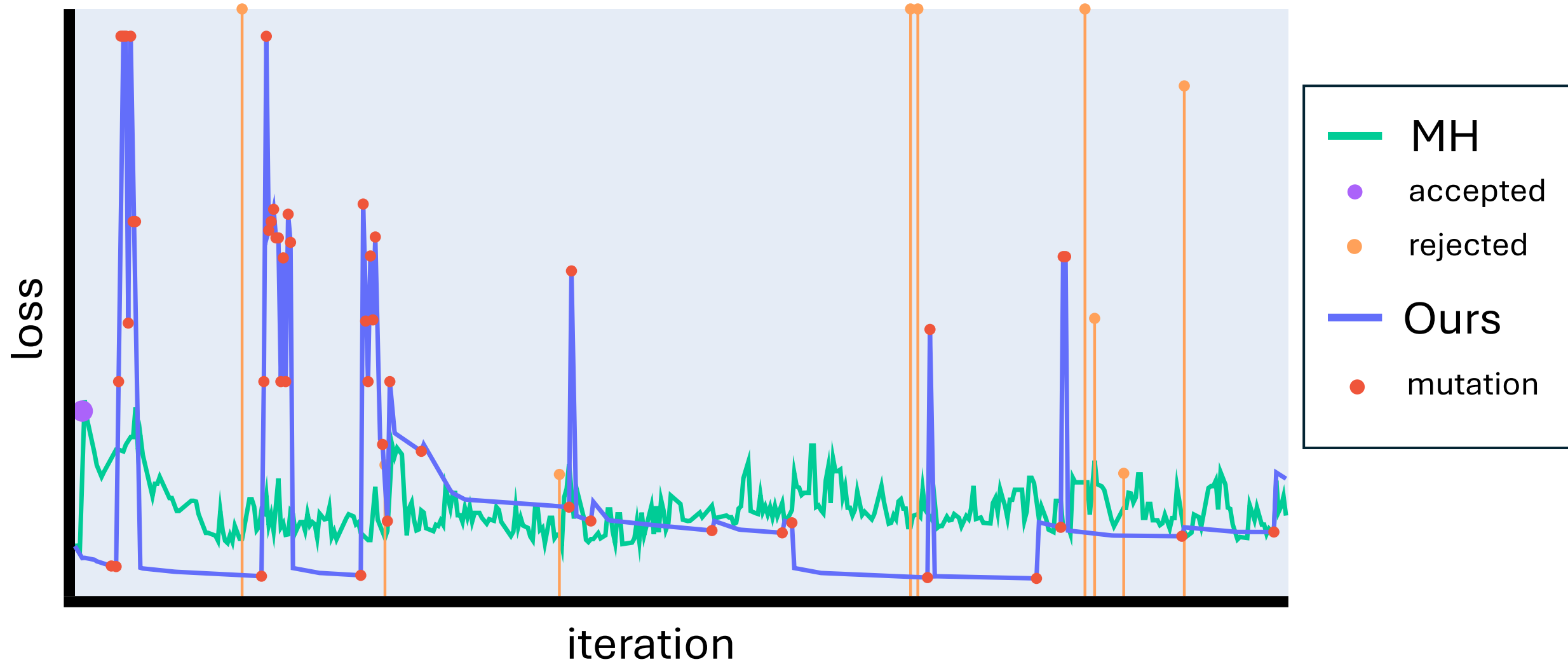
Langevin Monte Carlo (gradient descent) requires noise



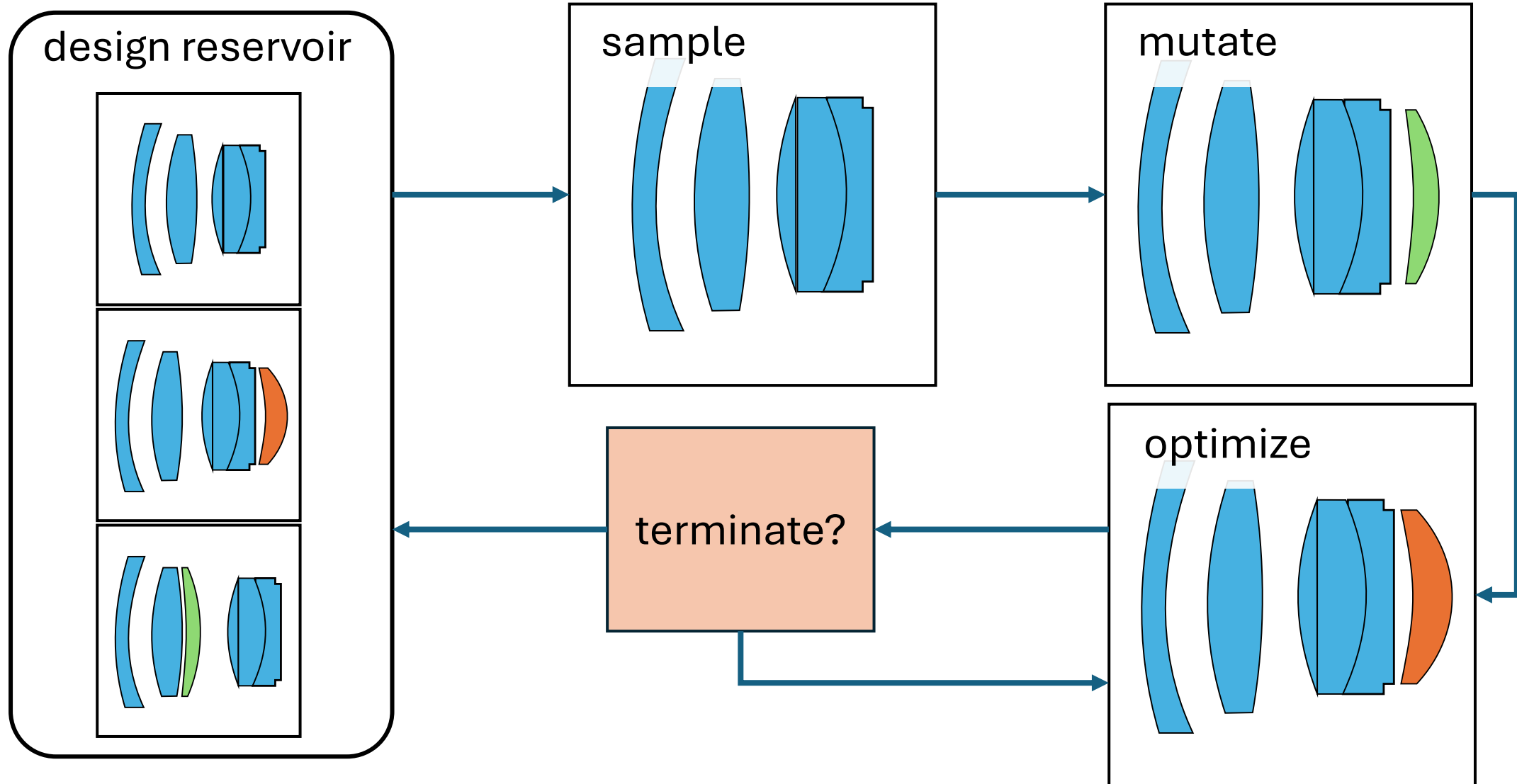
Lenses are sensitive to small changes



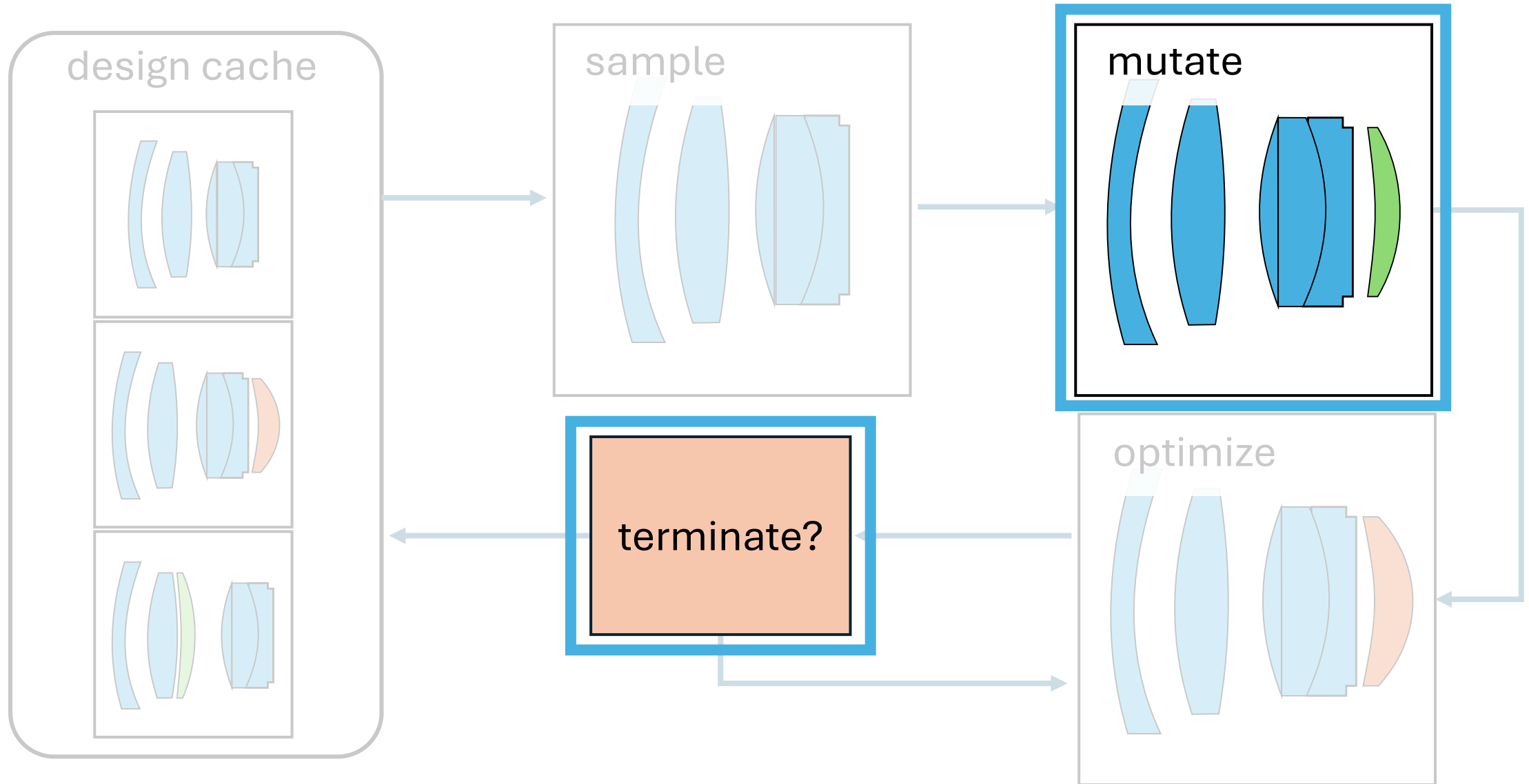
# Comparison to Metropolis-Hastings



# Quasi-stationary Monte Carlo (QSMC)



# Quasi-stationary Monte Carlo (QSMC)





# Stochastic termination

$$L\left(\left[\pi\right]\right)$$

Boltzmann distribution

$$\rho(\pi) = e^{-L(\pi)}$$

RESTORE

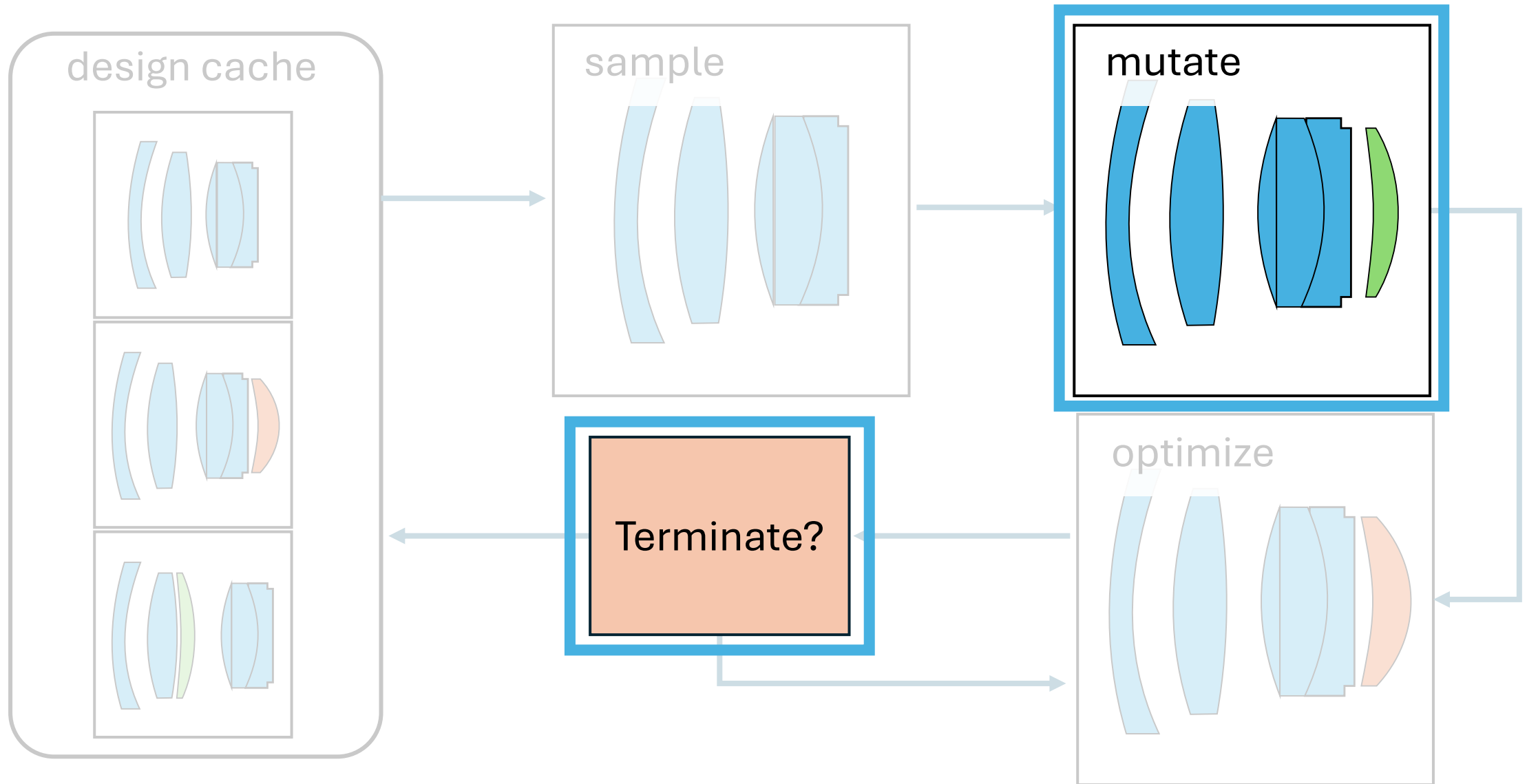
Jump Restore Light Transport  
[Holl et al. 2025]



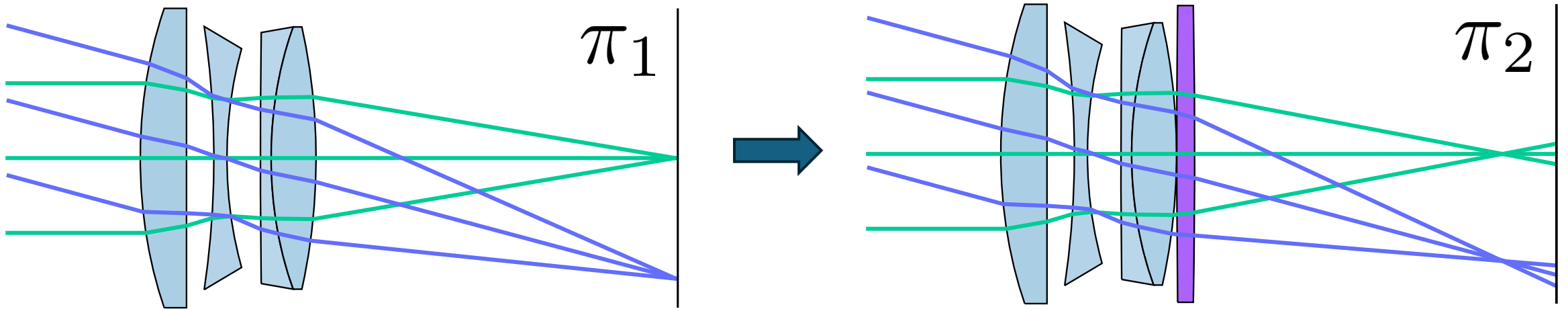
Probability of termination

$$\frac{\rho(\pi_{\text{prev}}) - \rho(\pi) + C}{\rho(\pi) + C}$$

# Quasi-Stationary Monte Carlo (QSMC)



# Simple mutations are problematic

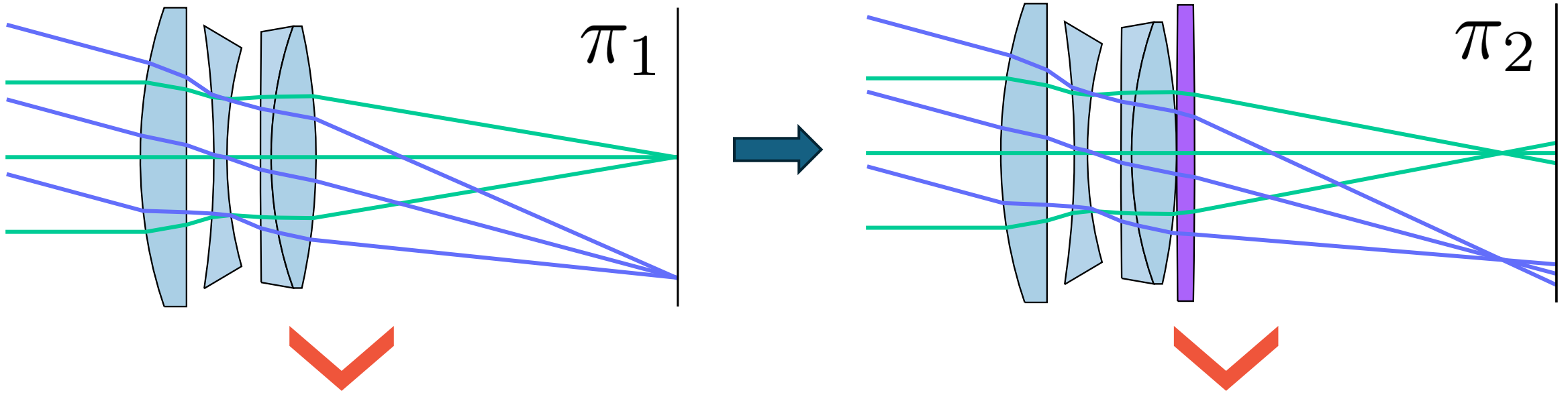


High chance of being a **worse** design

Most likely **terminated**



# Key idea: paraxial optics as a proxy



Ray transfer matrix

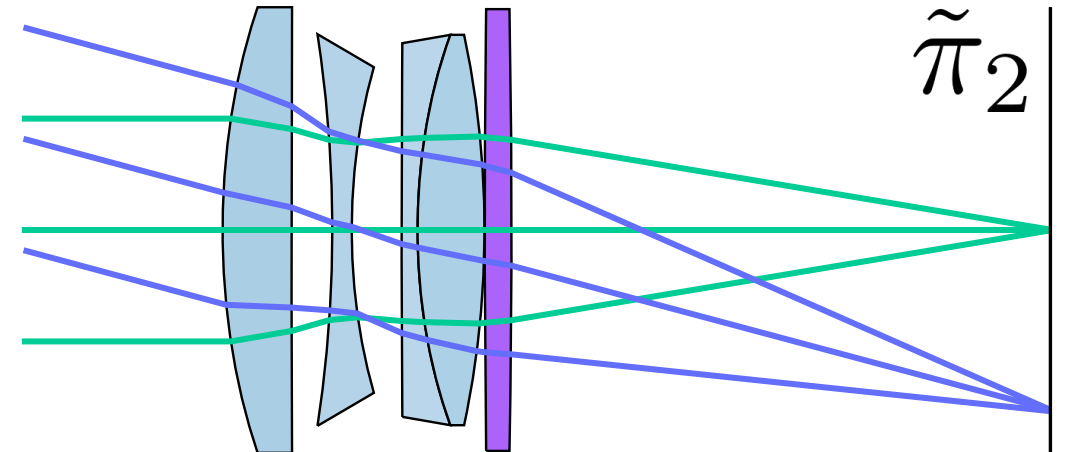
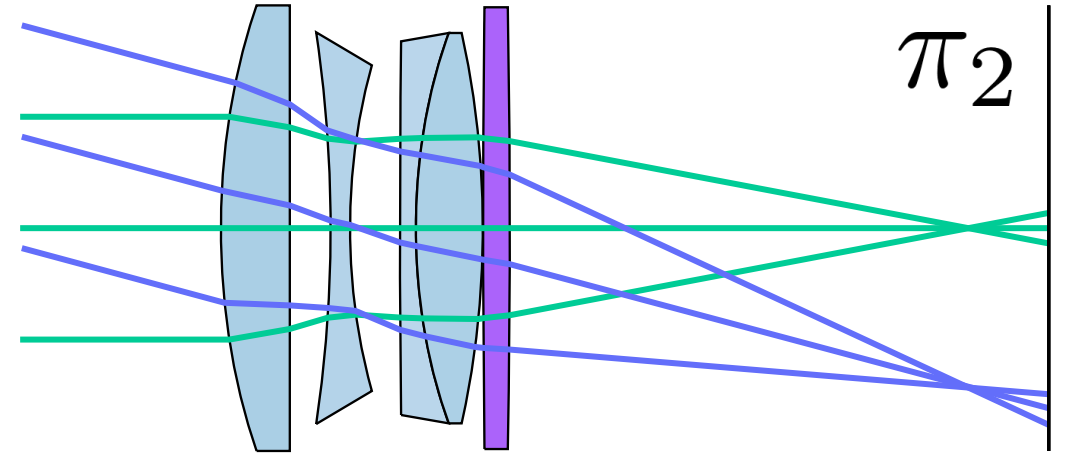
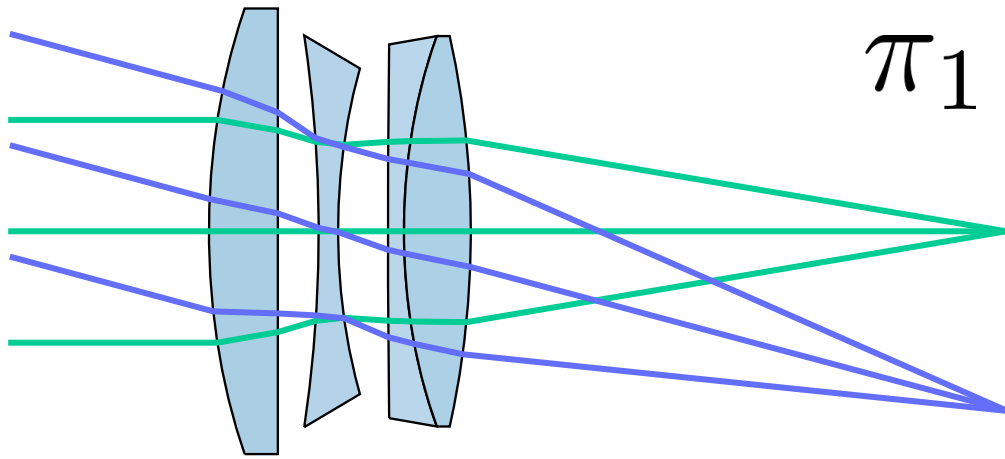
$$\mathbf{M}(\pi_1) = \begin{bmatrix} a & b \\ c & d \end{bmatrix}$$

$\neq$

Ray transfer matrix

$$\mathbf{M}(\pi_2) = \begin{bmatrix} a' & b' \\ c' & d' \end{bmatrix}$$

# Key idea: paraxial optics as a proxy

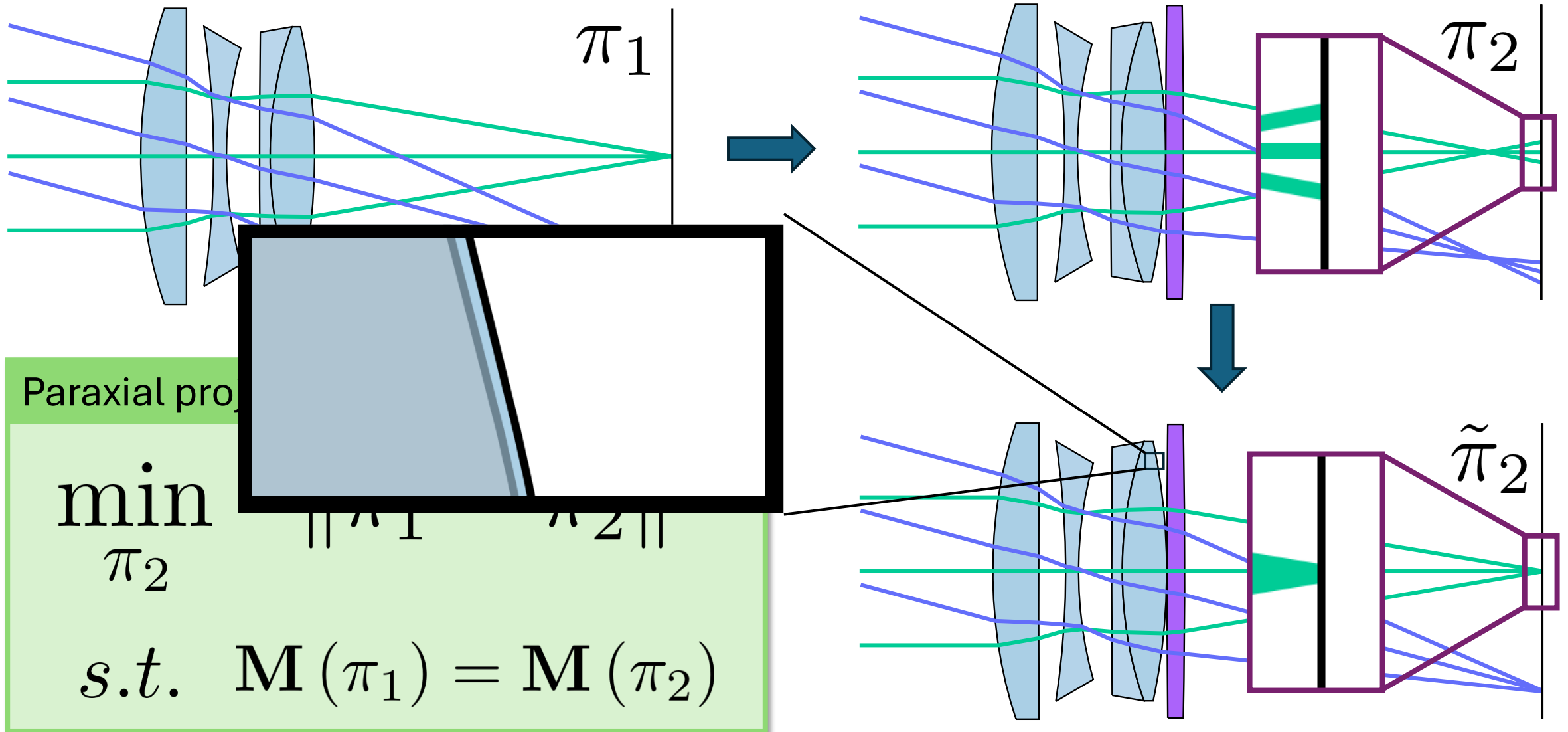


Paraxial projection

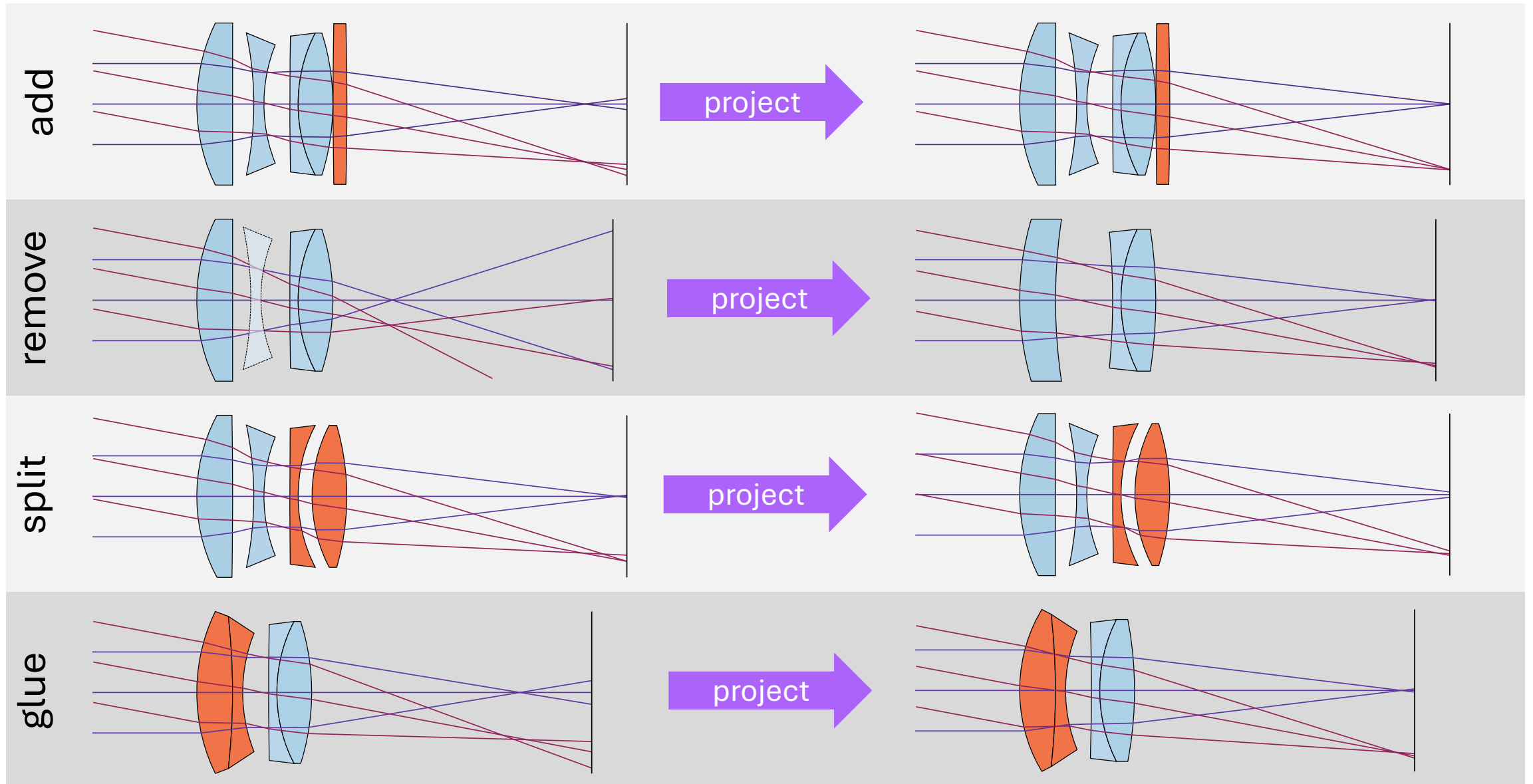
$$\min_{\pi_2} \quad \|\pi_1 - \pi_2\|^2$$

$$s.t. \quad \mathbf{M}(\pi_1) = \mathbf{M}(\pi_2)$$

# Key idea: paraxial optics as a proxy

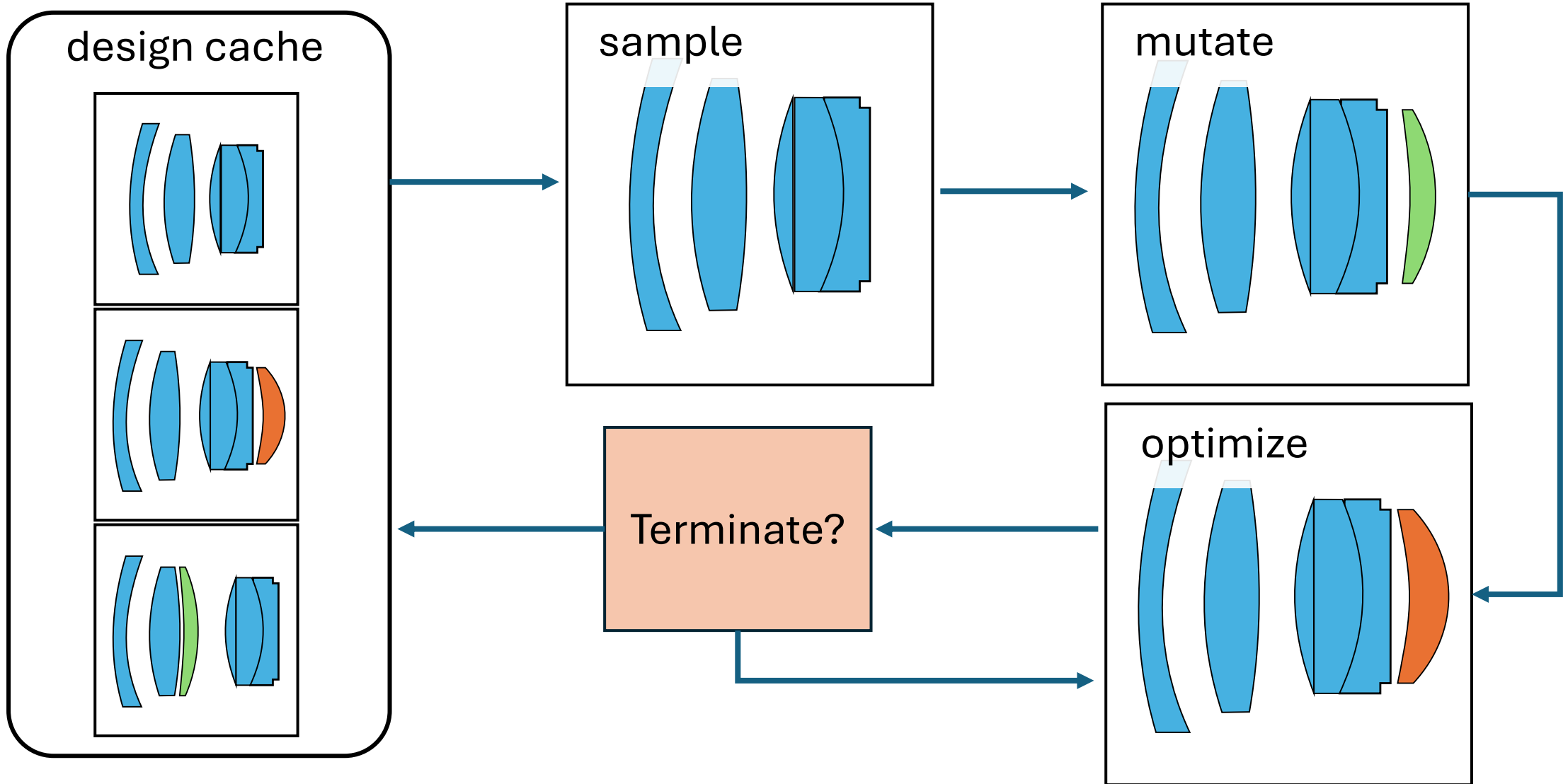


# Paraxial projection



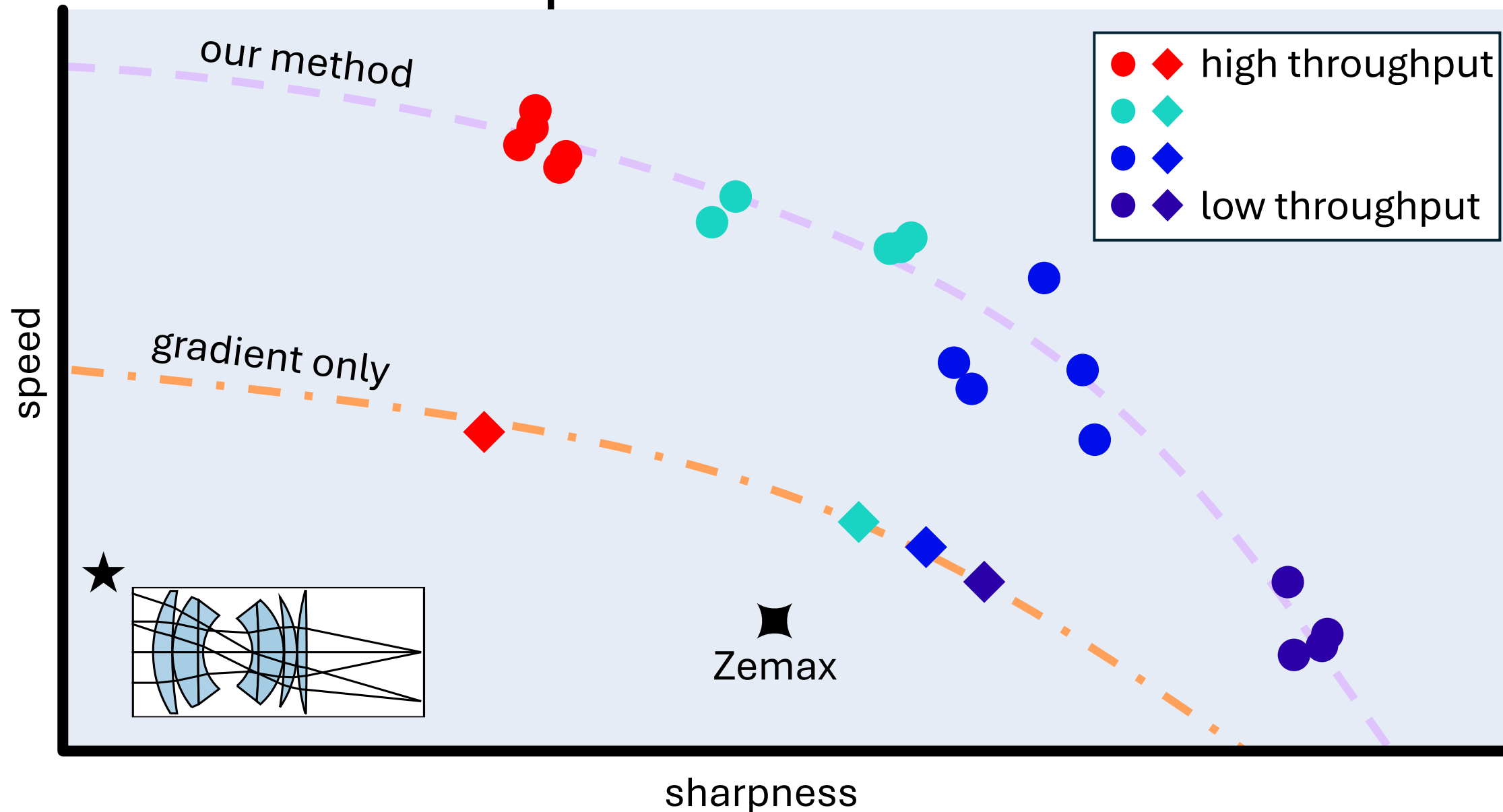


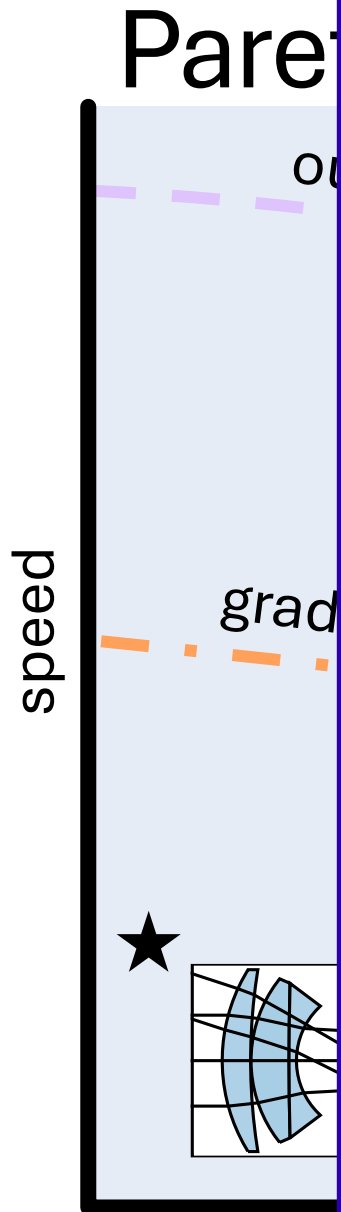
# Quasi-Stationary Monte Carlo (QSMC)



# Pareto front expansion

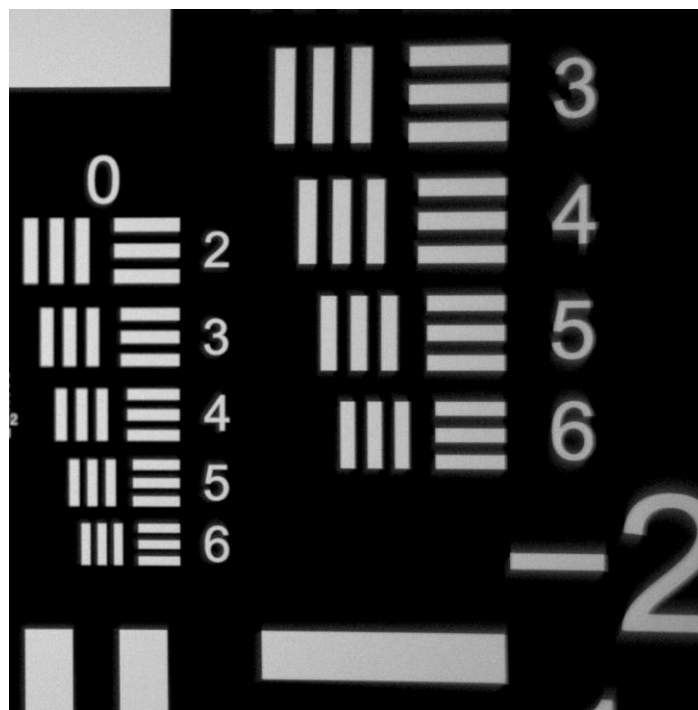
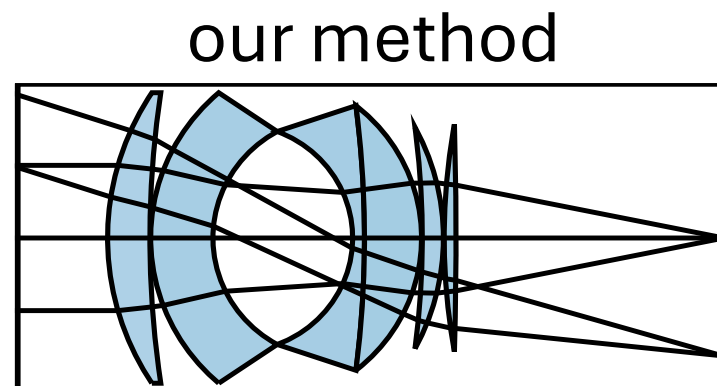
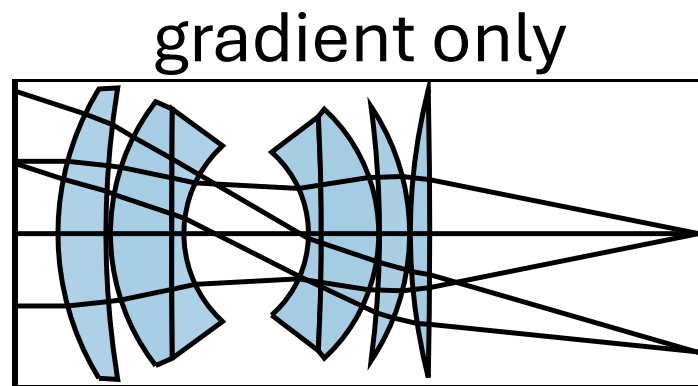
# Pareto front expansion



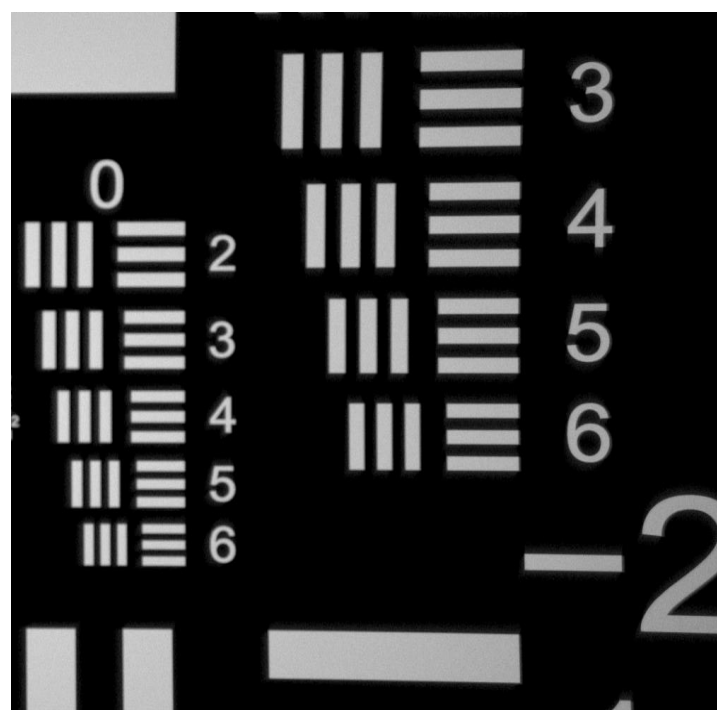


Pareto

high sharpness



$0.94I_0$



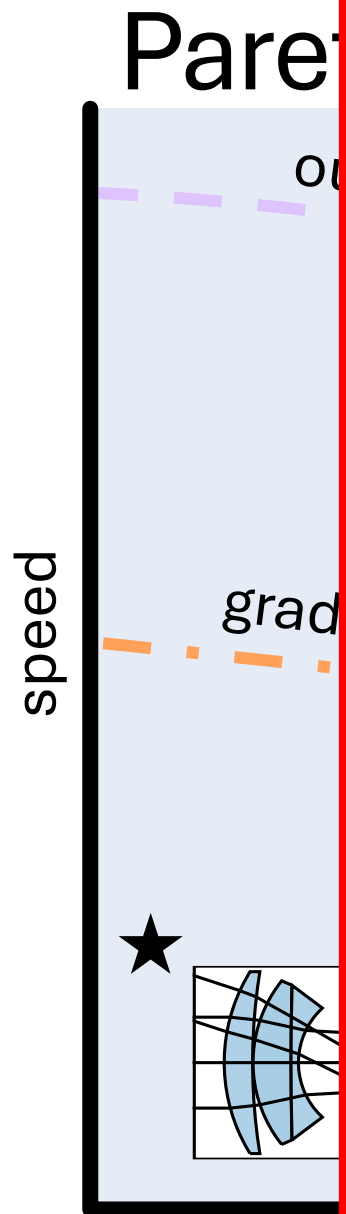
$0.92I_0$

sharpness

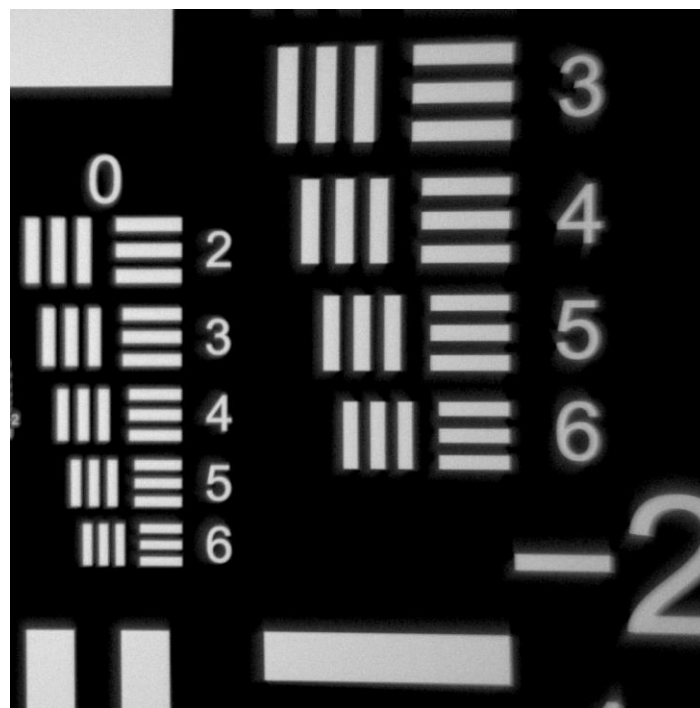
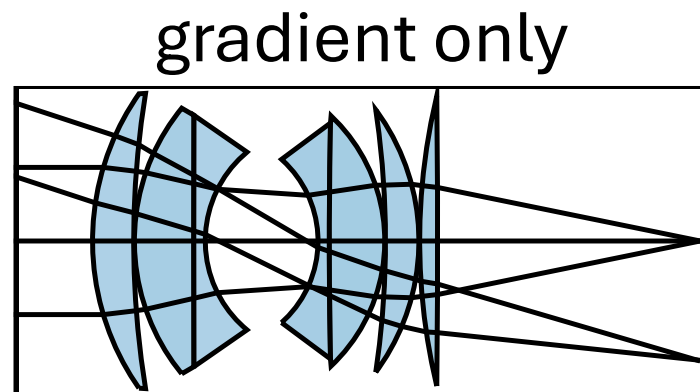
ghput

hput

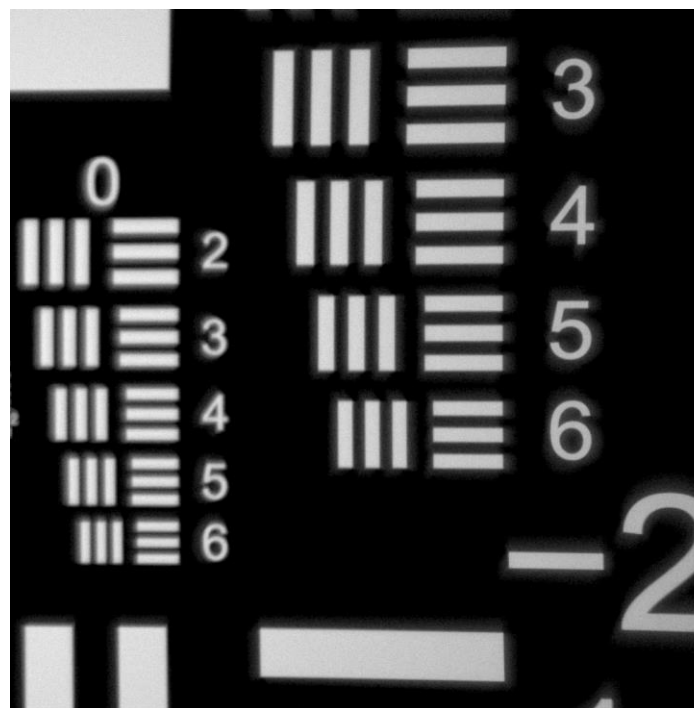
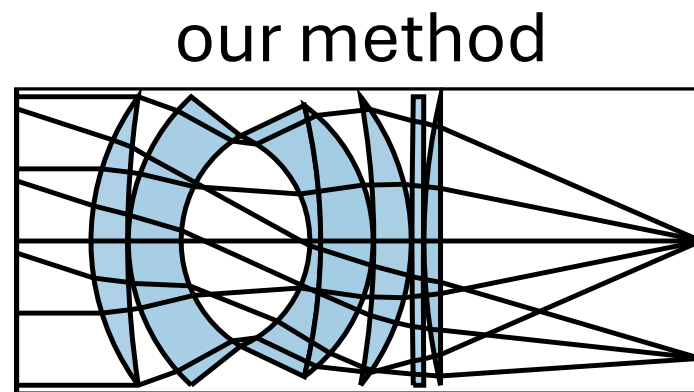




high throughput



$1.05I_0$



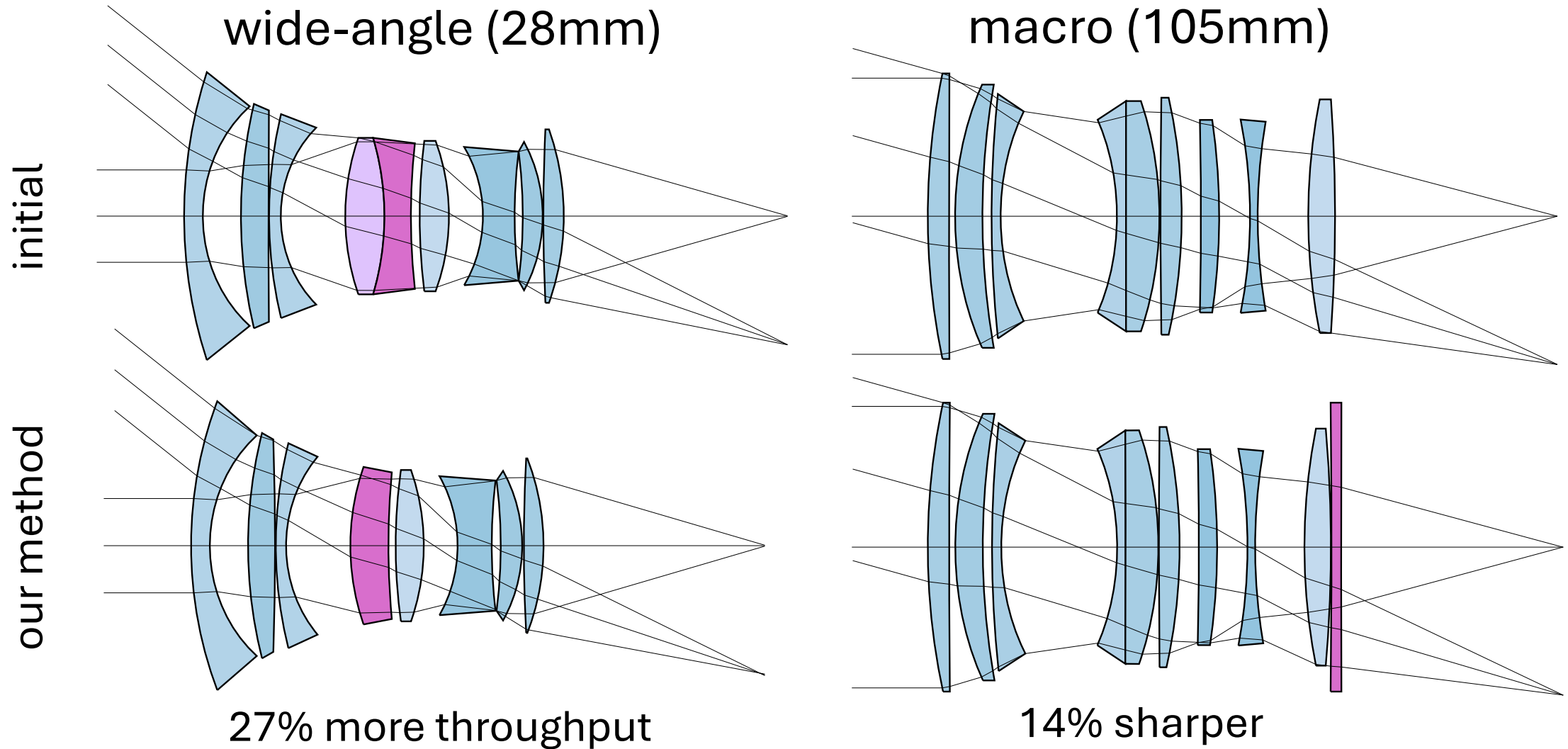
$1.09I_0$

highput

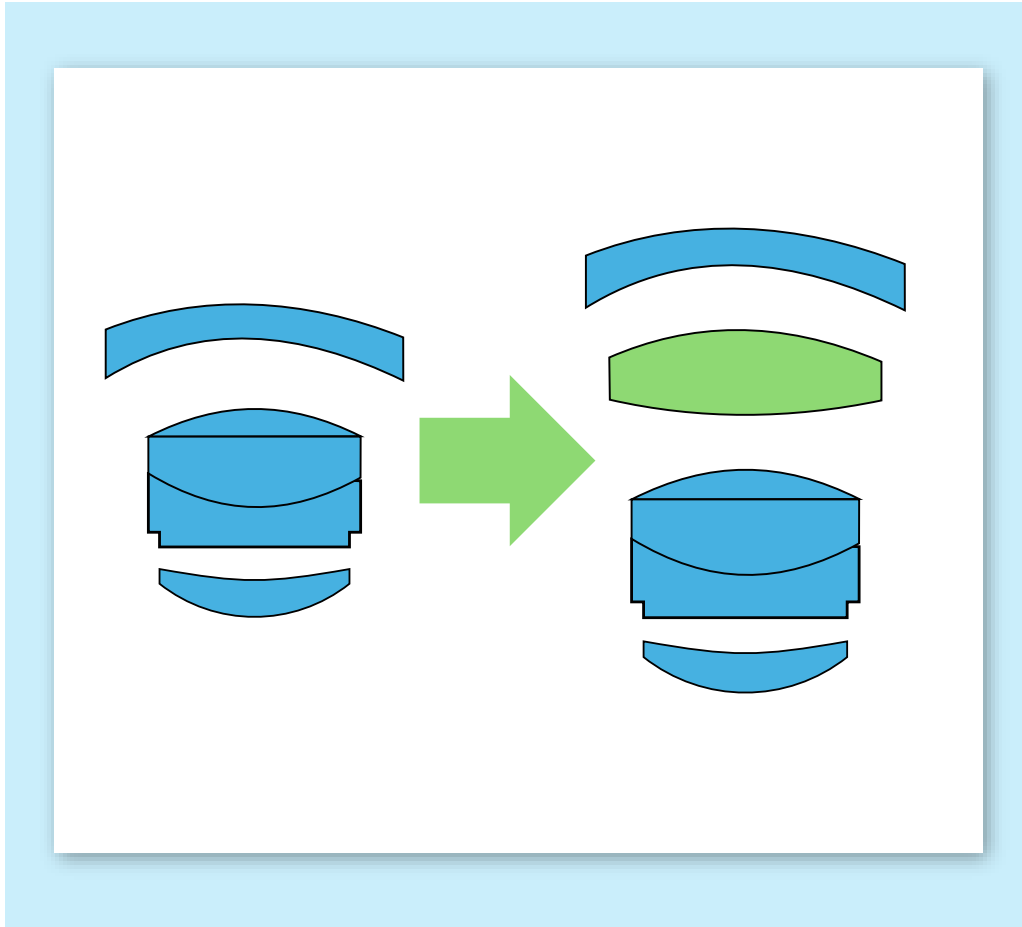
hput

sharpness

# Can improve other lens types as well



# Discrete-continuous optimization

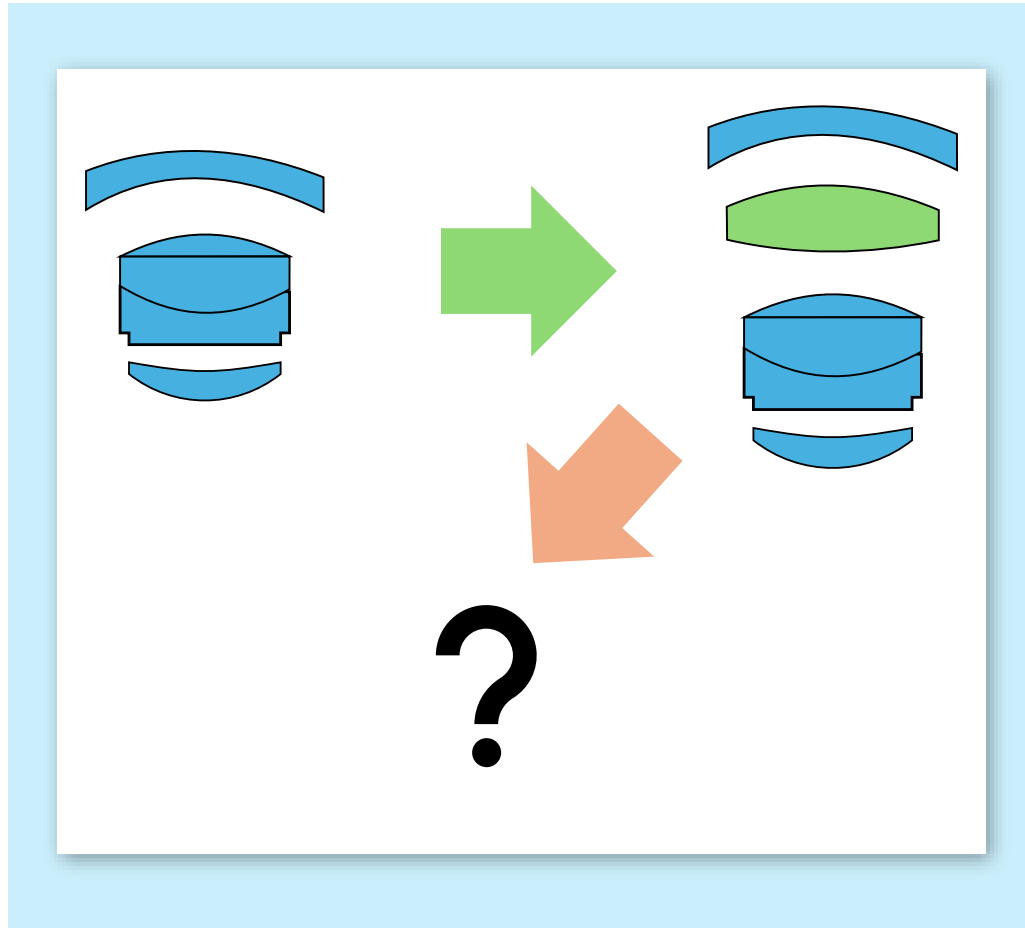


Optimization as a sampling problem

QSMC allows for optimization without noise

Better mutations with paraxial projection

# Our method is extendable



add aspheric, cylindrical, and other types of optics

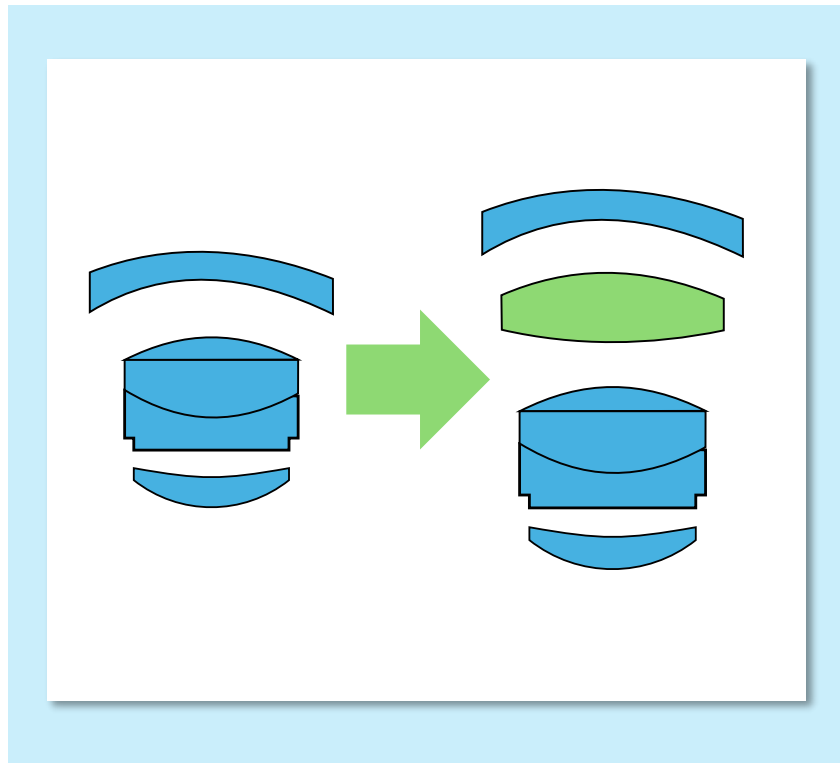
new design objectives to target specific aberrations

manufacturing and tolerance aware design



# Automated design of compound lenses with discrete-continuous optimization

Arjun Teh, Delio Vicini, Bernd Bickel, Matthew O'Toole, Ioannis Gkioulekas



ALFRED P. SLOAN  
FOUNDATION

[https://imaging.cs.cmu.edu/automated\\_lens\\_design/](https://imaging.cs.cmu.edu/automated_lens_design/)