Optimization of Optical Structures Using Machine Learning Algorithms

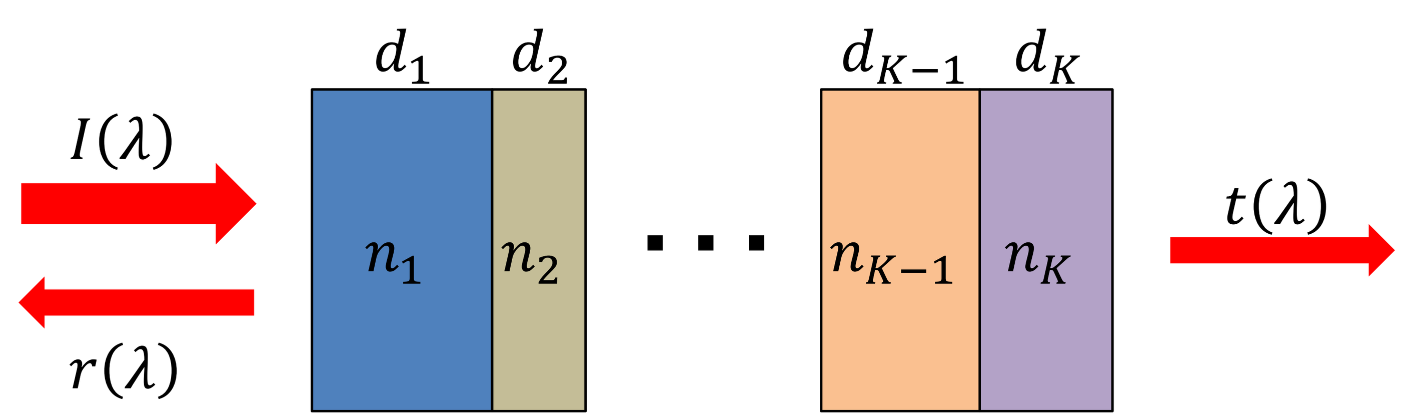
Tyler Hughes and Yu (Jerry) Shi

Introduction

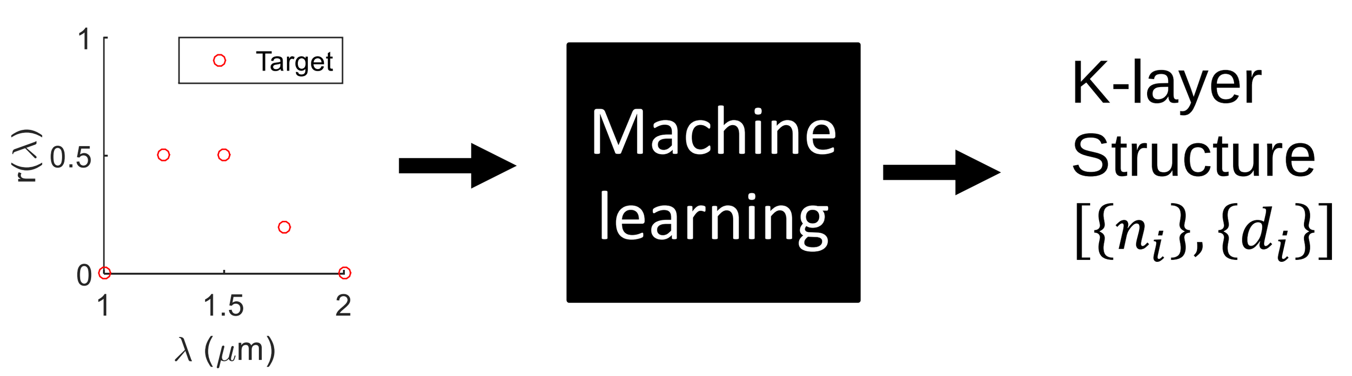
- In optical engineering, it is important to be able to **design devices with a desired reflection spectrum**
- Such designs are **nontrivial** and often rely on **complex** optimization algorithms
- We explore the use of machine learning algorithms to control the **reflection spectrum of a multi-layer structure**
- We show that **Markov Decision Process** produces structures with desired spectra

Background

- **Multi-layer structure**
  - Refractive indices: $\{n_1, \dots n_K\}$
  - Layer lengths: $\{d_1, \dots d_K\}$



- **Transfer matrix**: Given structure, can compute reflection, $r(\lambda)$.
- **Problem definition**: We wish to obtain structure parameters $[\{n_i\},\{d_i\}]$ that approximates a target spectrum $r(\{\lambda_i\})$.



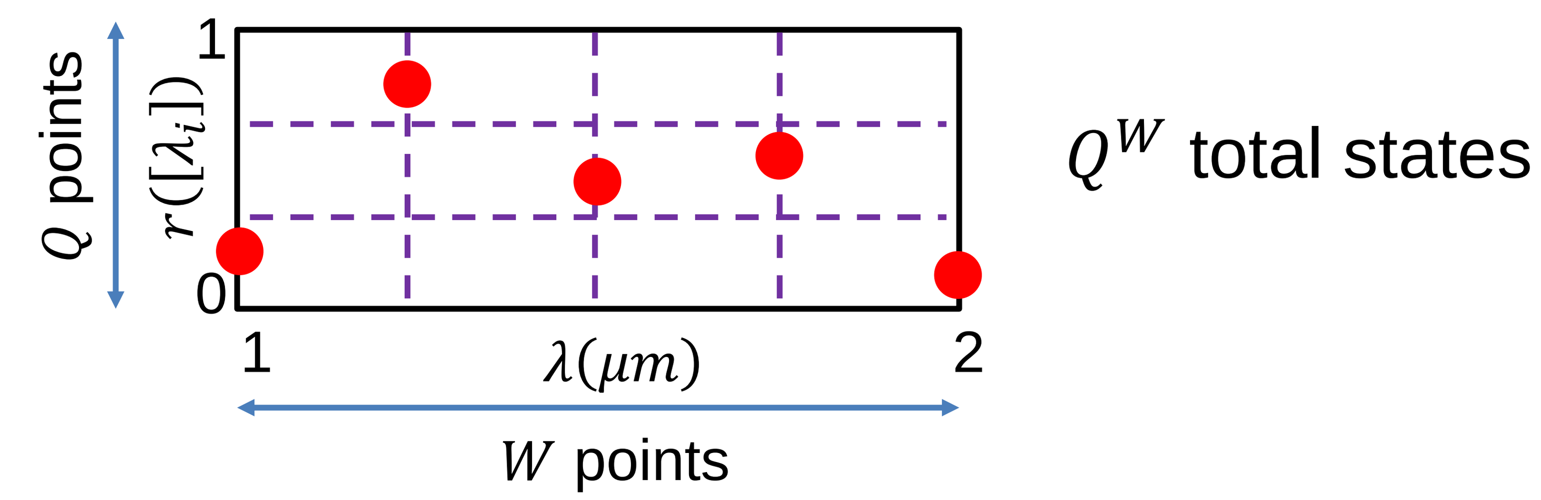
- **Challenge**: $[\{n_i\},\{d_i\}]$ varies highly nonlinearly with $r(\{\lambda_i\})$.

Markov Decision Process

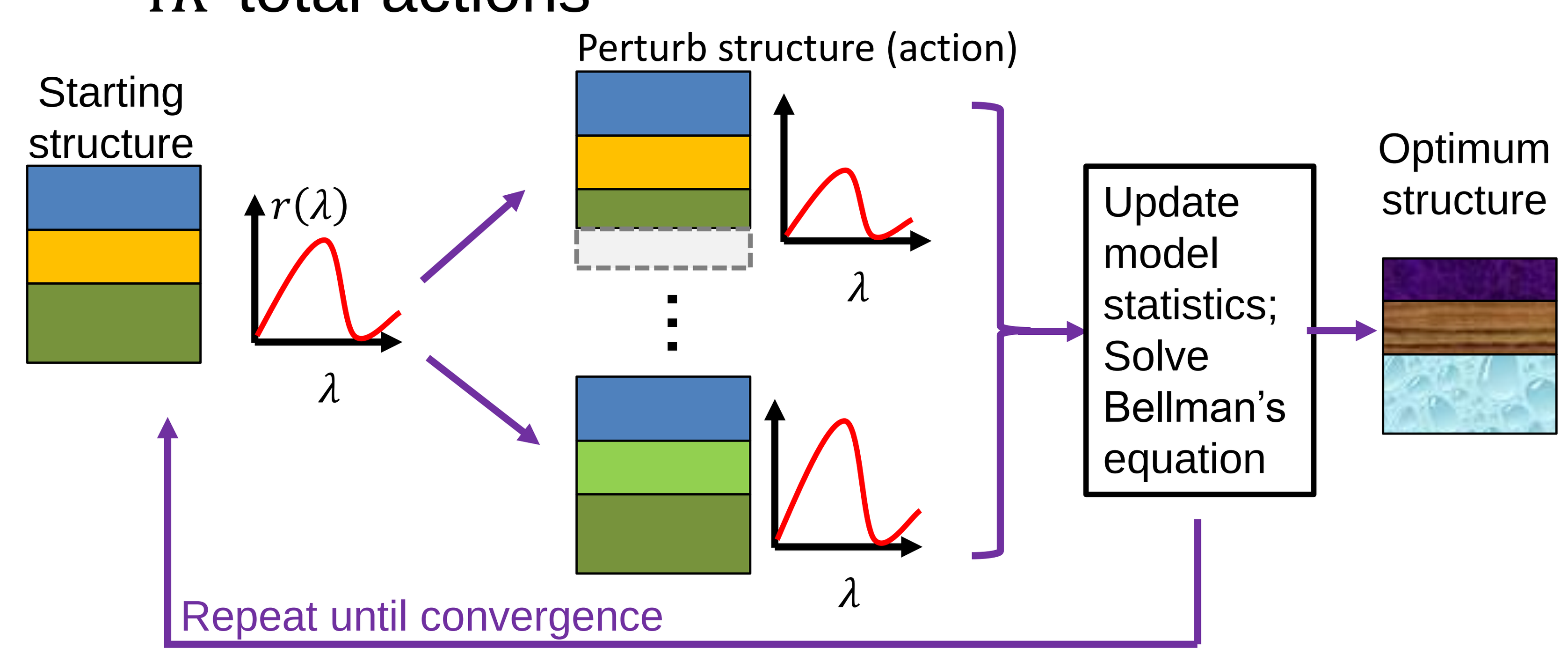
- **Objective:**
  - Given: $r_{target}(\{\lambda_i\})$
  - Find: $[\{n_i\},\{d_i\}]$ to minimize

$$J([\{n_i\},\{d_i\}]) \equiv \left\| r_{target} - r_{struc}([\{n_i\},\{d_i\}]) \right\|_2^2$$

- **Definitions and Procedure**
  - K = number of layers
  - W = number of points sampled in wavelengths
  - Q = number of points sampled in reflection
  - State: discretized reflection spectrum

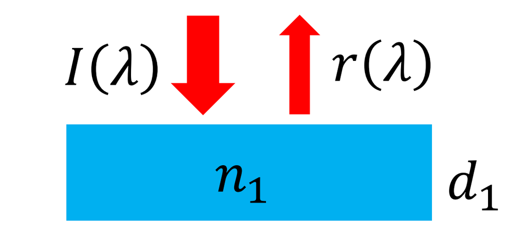


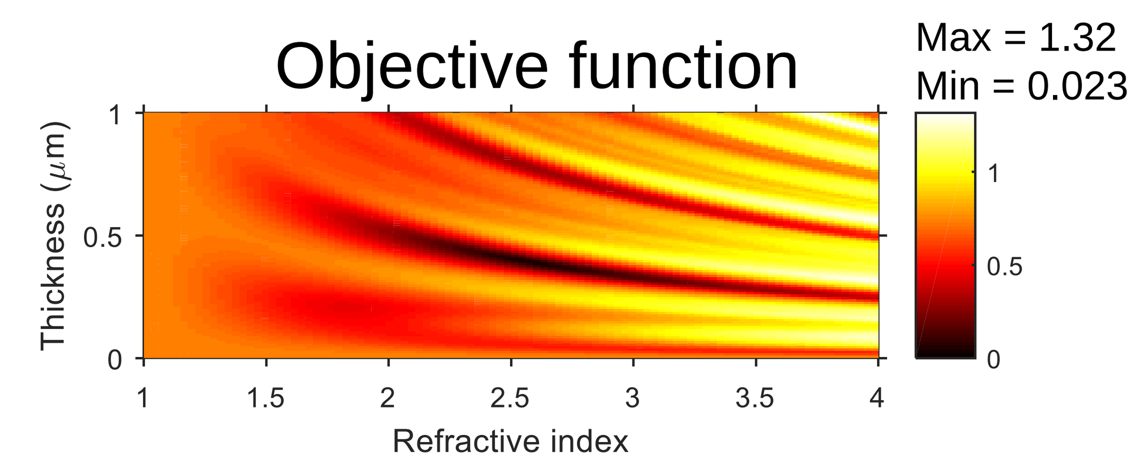
  - Reward: $R = -\left\| r_{target} - r_{struc}([\{n_i\},\{d_i\}]) \right\|_2^2$
  - Action: increase or decrease $[\{n_i\},\{d_i\}]$
    - $4K$ total actions

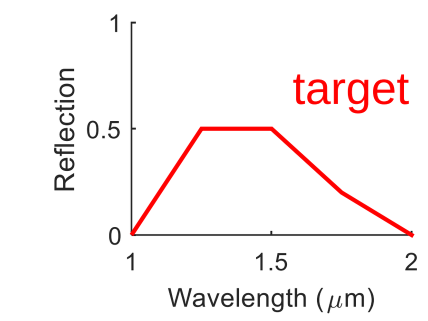


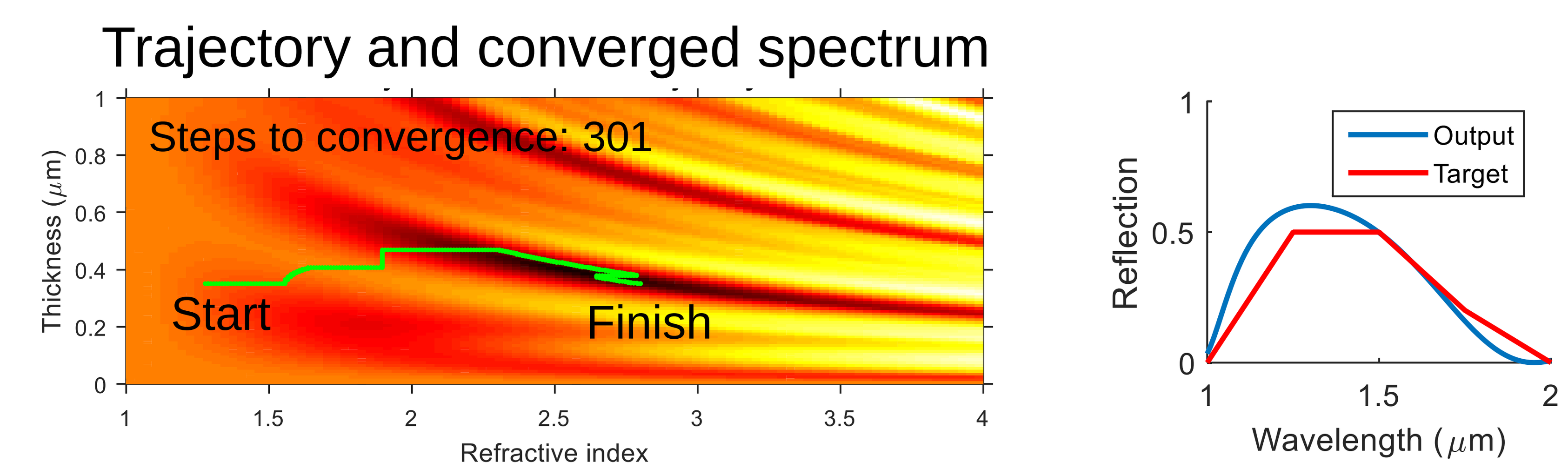
- **Advantages**
  - Computation complexity: # of spectra calculated
    MDP: $\sim \boldsymbol{K} Q^{2W}$
    Brute force: $\sim (Resolution)^{2\boldsymbol{K}}$
  - Immune to local minima

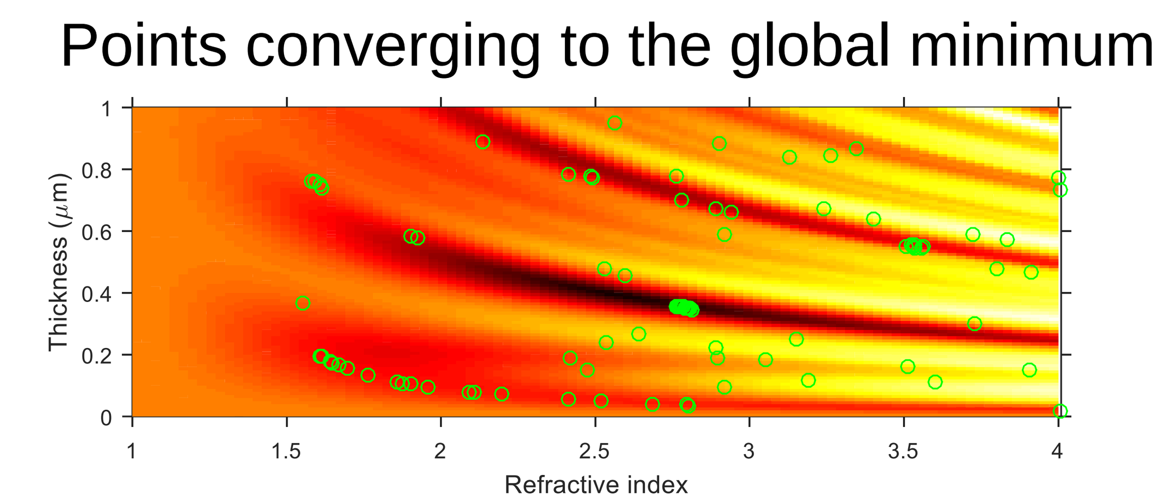
MDP Results



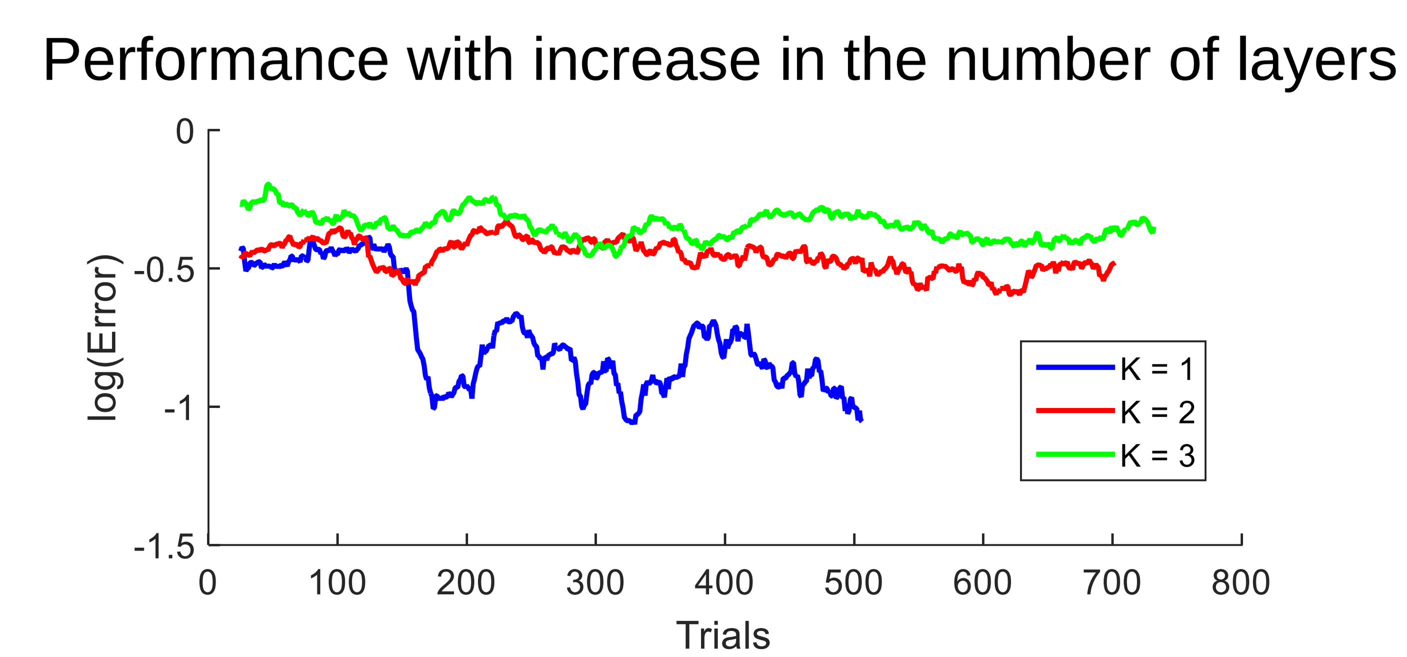








On average, **23.4%** of points fall around the global minimum



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