Gradient-Based Power Plant Design Using Differentiable Ray Tracing

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INTRO

Motivation

- Heliostat field is responsible for over 50% of the cost of solar tower power plants.
- Efficiently planned fields lower costs and increase yield through reduced shading or blocking effects.
- However, until today, fields are designed in a highly simplified way. Terrain, heliostat shape and focal spot shape are usually neglected or approximated.
- This is also due to a lack of numerical methods that provides useful gradients for energy transport in the field.

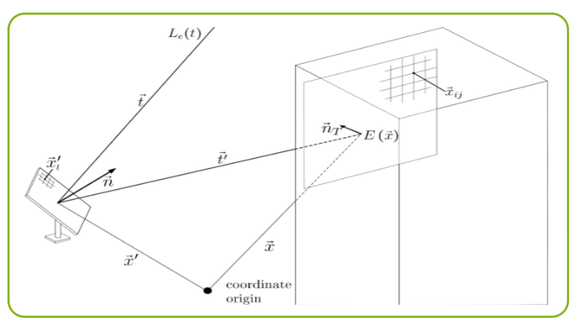
METHOD

$$E(\vec{x}_{ij}) = \sum_{\text{rays } k} \sum_{\text{pos } l} w_{ijk} \frac{1}{|t_l|^2} \rho(M_l \vec{t}_l) L_e(M_l \vec{t}_l) \vec{n}_T \cdot \vec{t}_l$$

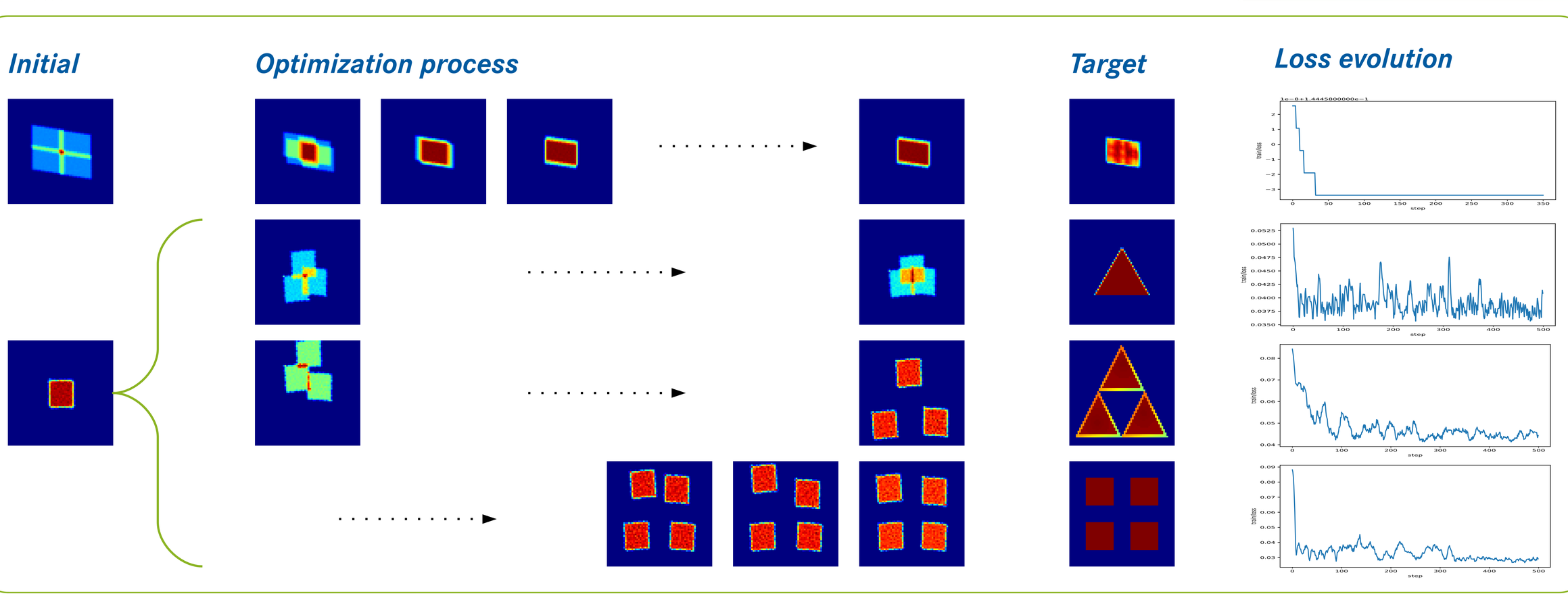
$$1 = \omega_{total} = \sum_{\text{rays } k} \sum_{0<n<N} 1 - \left(\frac{\vec{x}_k - \vec{x}_n}{\Sigma(\vec{x}_k - \vec{x}_n)} \right)$$

Differentiable ray tracing

- Provide a differentiable description of energy transport in the field, resulting in simulated flux density maps.
- Enables a gradient-based optimization of classical ray tracing methods.
- Find a suitable error (“loss”) function comparing simulation to real/given flux density maps.
- Differentiable formulation allows taking derivatives wrt. any parameters (if their effect in the ray tracer is differentiable).
- Allows (simultaneous) optimization of any parameters with gradients != 0:
  - Heliostat position, mirror surface shape, …
- Can simulate (and optimize in) highly realistic simulated environments due to ray tracing method. Additional possibilities:
  - Field on slope/hilly landscape, weather data, …



RESULTS



OUTLOOK

- Stable algorithm, but more stability preferable. Optimization configuration may need adjustments for different targets.
- Almost any other parameter optimizations also possible!
  Due to differentiable formulation and sophisticated software framework, optimizing new/different parameters becomes a piece of cake.
- Test with even more heliostats, farther positions (i.e. complete field optimization).
  Test on measured and pre-simulated flux density maps for complete field.
- Include shading and blocking in ray tracer.
- ***Be sure to check out the oral “In Situ Enhancement of Heliostat Calibration Using Differentiable Ray Tracing” on Thu 29, 09:30 at San Miguel (215)!***

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