Uniform Light Optimization for a Greenhouse

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Background

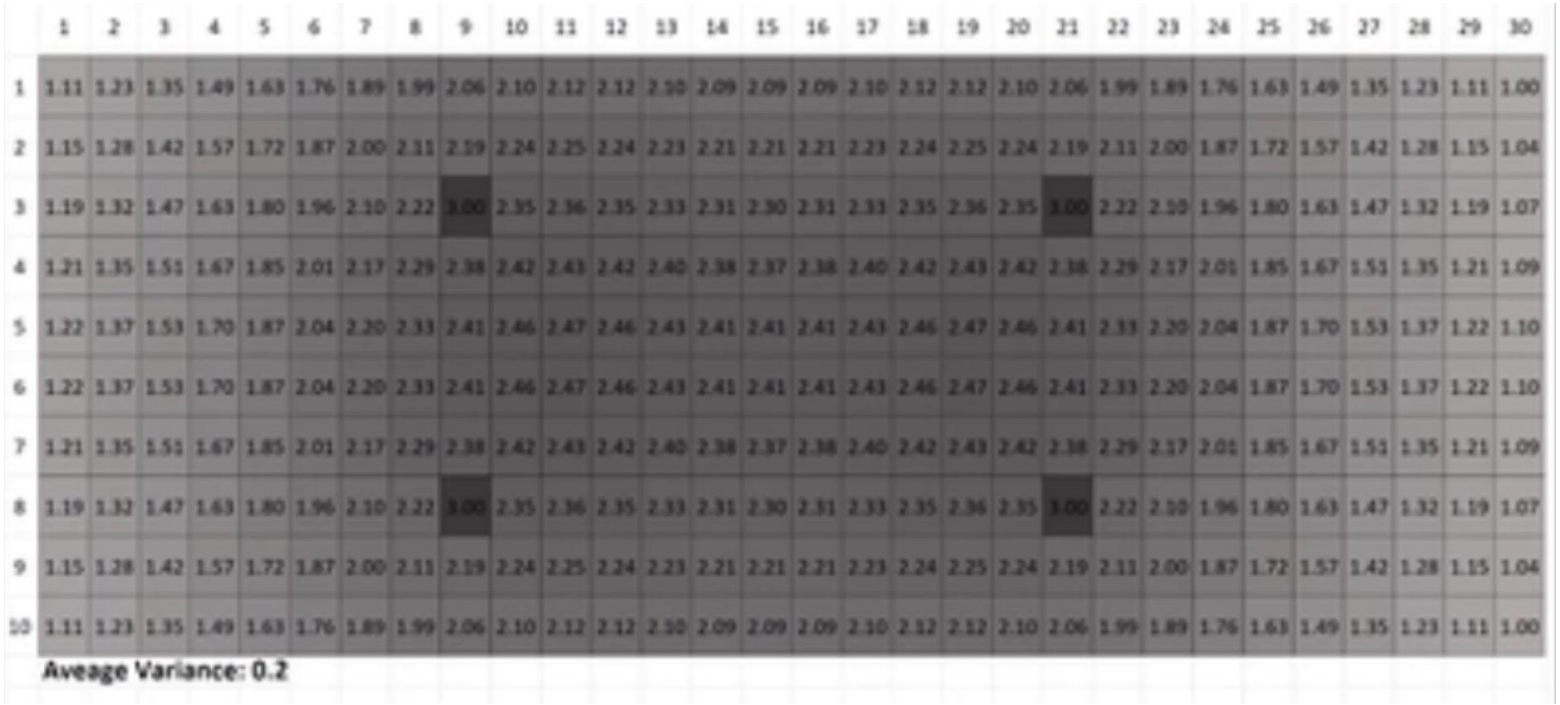
Need for concentrated, supplemental lighting in greenhouses

Background

Uniform distribution of light is essential to prevent uneven growth

The Problem

3D optimization of light sources on discretized target surface



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
1	1.11	1.23	1.35	1.49	1.63	1.76	1.89	1.99	2.06	2.10	2.12	2.12	2.10	2.09	2.09	2.09	2.10	2.12	2.12	2.10	2.06	1.99	1.89	1.76	1.63	1.49	1.35	1.23	1.11	1.00
2	1.15	1.28	1.42	1.57	1.72	1.87	2.00	2.11	2.19	2.24	2.25	2.24	2.23	2.21	2.21	2.21	2.23	2.24	2.25	2.24	2.19	2.11	2.00	1.87	1.72	1.57	1.42	1.28	1.15	1.04
3	1.19	1.32	1.47	1.63	1.80	1.96	2.10	2.22	3.00	2.35	2.36	2.35	2.33	2.31	2.30	2.31	2.33	2.35	2.36	2.35	3.00	2.22	2.10	1.96	1.80	1.63	1.47	1.32	1.19	1.07
4	1.21	1.35	1.51	1.67	1.85	2.01	2.17	2.29	2.38	2.42	2.43	2.42	2.40	2.38	2.37	2.38	2.40	2.42	2.43	2.42	2.38	2.29	2.17	2.01	1.85	1.67	1.51	1.35	1.21	1.09
5	1.22	1.37	1.53	1.70	1.87	2.04	2.20	2.33	2.41	2.46	2.47	2.46	2.43	2.41	2.41	2.41	2.43	2.46	2.47	2.46	2.41	2.33	2.20	2.04	1.87	1.70	1.53	1.37	1.22	1.10
6	1.22	1.37	1.53	1.70	1.87	2.04	2.20	2.33	2.41	2.46	2.47	2.46	2.43	2.41	2.41	2.41	2.43	2.46	2.47	2.46	2.41	2.33	2.20	2.04	1.87	1.70	1.53	1.37	1.22	1.10
7	1.21	1.35	1.51	1.67	1.85	2.01	2.17	2.29	2.38	2.42	2.43	2.42	2.40	2.38	2.37	2.38	2.40	2.42	2.43	2.42	2.38	2.29	2.17	2.01	1.85	1.67	1.51	1.35	1.21	1.09
8	1.19	1.32	1.47	1.63	1.80	1.96	2.10	2.22	3.00	2.35	2.36	2.35	2.33	2.31	2.30	2.31	2.33	2.35	2.36	2.35	3.00	2.22	2.10	1.96	1.80	1.63	1.47	1.32	1.19	1.07
9	1.15	1.28	1.42	1.57	1.72	1.87	2.00	2.11	2.19	2.24	2.25	2.24	2.23	2.21	2.21	2.21	2.23	2.24	2.25	2.24	2.19	2.11	2.00	1.87	1.72	1.57	1.42	1.28	1.15	1.04
10	1.11	1.23	1.35	1.49	1.63	1.76	1.89	1.99	2.06	2.10	2.12	2.12	2.10	2.09	2.09	2.09	2.10	2.12	2.12	2.10	2.06	1.99	1.89	1.76	1.63	1.49	1.35	1.23	1.11	1.00

Aveage Variance: 0.2

The Problem

3D optimization of light sources on discretized target surface

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
1	1.40	1.51	1.60	1.67	1.71	1.73	1.72	1.70	1.67	1.63	1.59	1.56	1.53	1.51	1.50	1.50	1.51	1.53	1.55	1.58	1.61	1.64	1.67	1.68	1.68	1.67	1.62	1.56	1.47	1.36
2	1.47	1.59	1.69	1.77	1.82	1.84	1.83	1.81	1.78	1.74	1.70	1.66	1.63	1.60	1.59	1.59	1.60	1.62	1.65	1.68	1.72	1.75	1.77	1.79	1.79	1.76	1.71	1.64	1.54	1.42
3	1.51	1.64	1.75	3.00	1.90	1.92	1.93	1.91	1.88	1.84	1.79	1.75	1.72	1.69	1.68	1.68	1.69	1.72	1.75	1.78	1.82	1.84	1.86	1.87	1.86	1.83	3.00	1.69	1.58	1.46
4	1.53	1.66	1.78	1.88	1.94	1.98	2.00	1.99	1.96	1.92	1.88	1.83	1.79	1.77	1.75	1.76	1.77	1.80	1.83	1.87	1.90	1.92	1.93	1.93	1.91	1.87	1.80	1.71	1.60	1.47
5	1.52	1.65	1.78	1.88	1.96	2.01	2.04	2.04	2.02	1.99	1.95	1.90	1.86	1.83	1.81	1.82	1.84	1.87	1.90	1.94	1.97	1.98	1.98	1.96	1.93	1.87	1.80	1.70	1.58	1.46
6	1.49	1.62	1.74	1.85	1.94	2.01	2.05	2.06	2.06	2.03	1.99	1.94	1.90	1.87	1.86	1.86	1.88	1.91	1.95	1.99	2.01	2.01	2.00	1.97	1.92	1.85	1.76	1.66	1.54	1.42
7	1.44	1.56	1.69	1.80	1.89	1.97	2.03	2.05	2.06	2.04	2.00	1.96	1.92	1.89	1.87	1.88	1.90	1.93	1.97	2.00	2.02	2.01	1.98	1.94	1.87	1.80	1.70	1.60	1.49	1.37
8	1.37	1.49	1.61	1.72	1.82	1.91	1.97	2.01	3.00	2.01	1.98	1.94	1.90	1.87	1.86	1.86	1.89	1.92	1.95	1.98	3.00	1.98	1.94	1.88	1.81	1.72	1.63	1.52	1.42	1.30
9	1.30	1.42	1.53	1.63	1.73	1.82	1.89	1.93	1.95	1.95	1.92	1.89	1.86	1.83	1.82	1.82	1.84	1.87	1.90	1.92	1.93	1.91	1.86	1.80	1.72	1.64	1.54	1.44	1.34	1.23
10	1.23	1.33	1.43	1.53	1.63	1.71	1.78	1.83	1.85	1.85	1.84	1.81	1.78	1.76	1.75	1.76	1.77	1.80	1.82	1.83	1.83	1.81	1.76	1.70	1.62	1.54	1.44	1.35	1.26	1.16

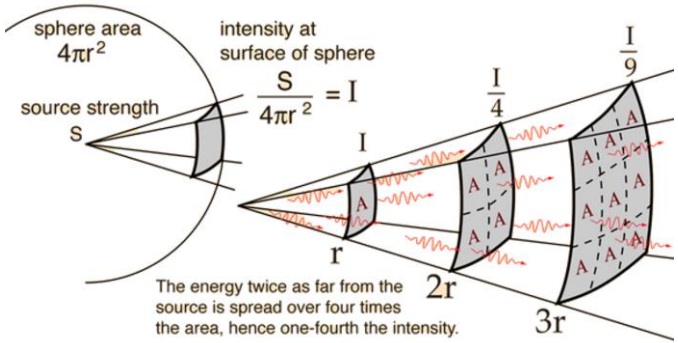
Aveage Variance: 0.05

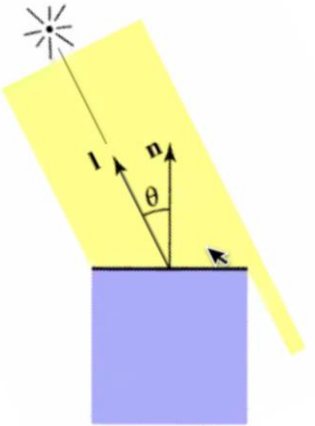
Approach and Problem Formulation

Non-convex NLP problem

$$I_{ijk} = \frac{K_i}{r_{ijk}^2} Cos\theta$$

$$r_{ijk} = \sqrt{(X_i - X_p)^2 + (Y_i - Y_p)^2 + (Z_i - Z_p)^2}$$





Objective function:

$$Min \sum_{ijk} \left[\frac{(I_{ijk} - I_{Average})2}{n} \right]$$

Approach and Problem Formulation

Non-convex NLP problem

$$Min \quad \sum_{ijk} \left[\frac{(\mathrm{I_{ijk}} - \mathrm{I}_{Average})2}{n} \right]$$

Decision Variables:

Light source location – $X_i; Y_i; Z_i$

Grid intensity – I_{ij}

Constraints:

$$I_{min} \leq I_{ij}$$

$$0 \leq X_i \leq GH_{x-max}$$

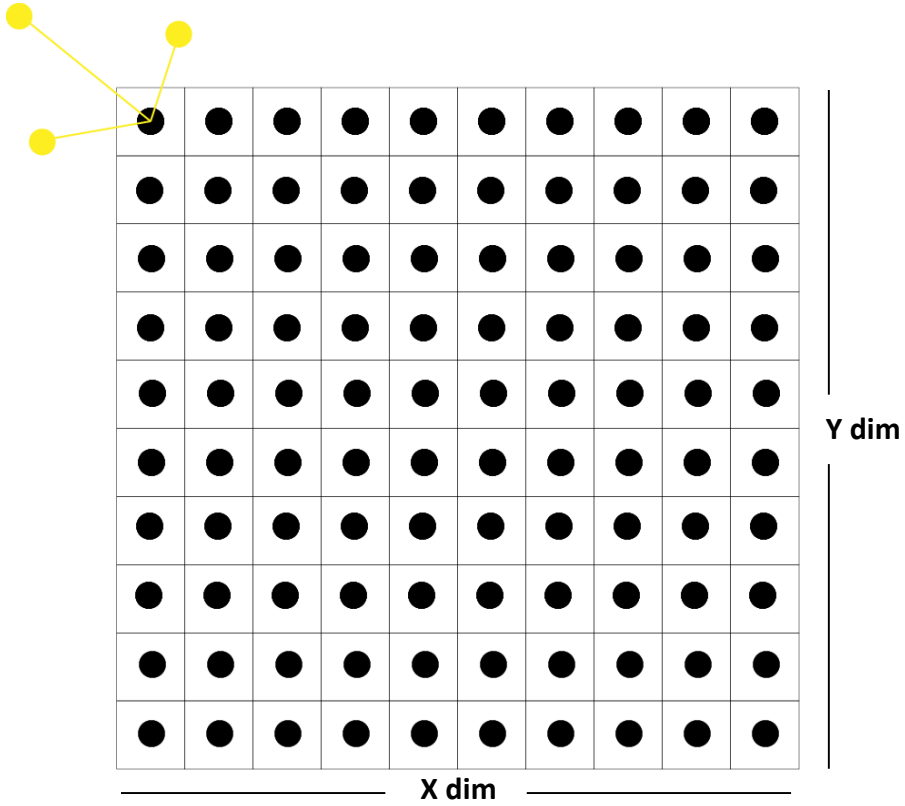
$$0 \leq Y_i \leq GH_{y-max}$$

$$0 \leq Z_i \leq GH_{z-max}$$

$$\left(X_i - X_j\right)^2 + \left(Y_i - Y_j\right)^2 \leq \varepsilon$$

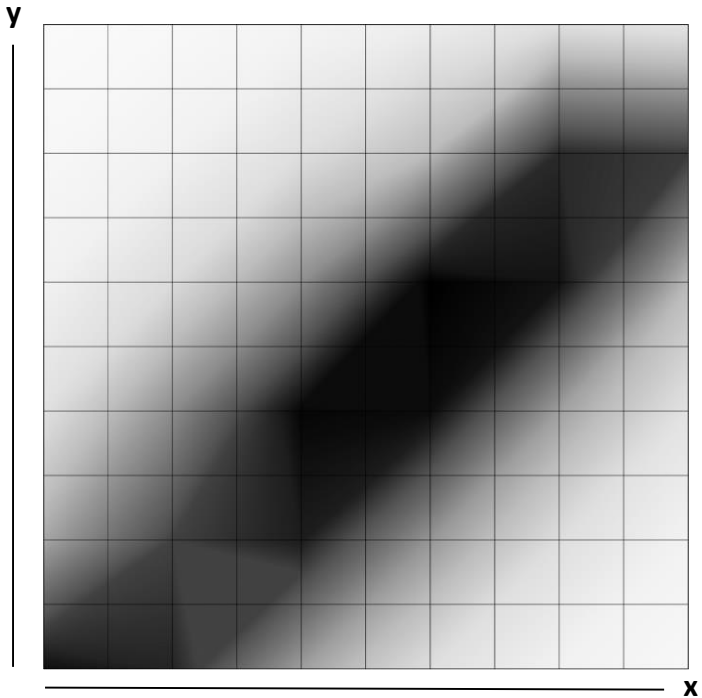
Algorithm and Solving Process

Converting the set of equations into code



Case Study and Results

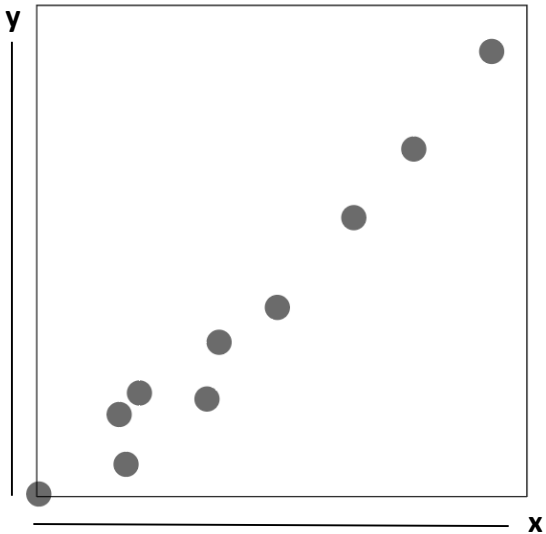
Parameters: 100 x 100 x 10 room, 10 x 10 grid, 10 light sources



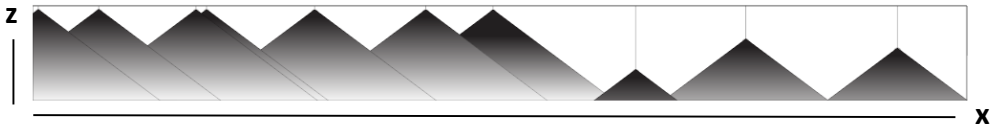
Target Surface Intensities

Position of Lights

Top View

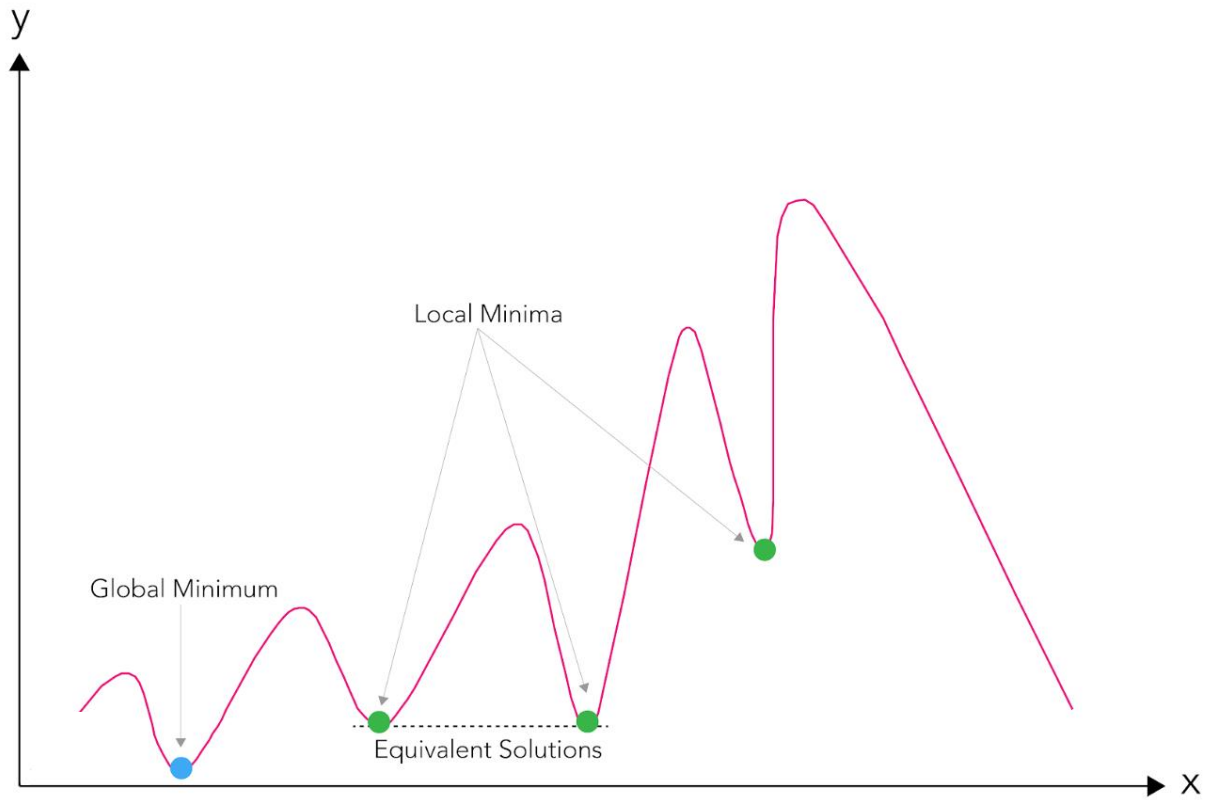


Section View



Case Study and Results

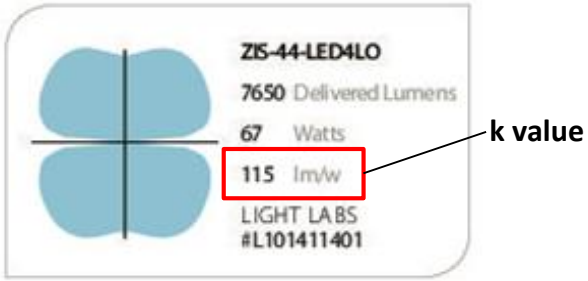
Non-convexity related complications



Moving Forward

Incorporating uncertainty, MINLP formulation, multi-objective function

Uncertainty in manufacturer's specs



Uncertainty in daylight integration

Multi-objective optimization: minimize variance + maximize intensity


Thank You
Questions?