Sloppy and Genetic Algorithms for Low-Emittance Tuning at CESR

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CESR
Sloppy Models
Problem Statement

• Minimize one objective (vertical emittance/beam size)
• Large number of decision variables (independent magnets)
• No reliable auxiliary information (dispersion, coupling)
• Reliable model of machine responses (BMAD simulation)
Sloppy Models

Simulated Results
Experimental Results

![Experimental Results Graphs](image)

Entries | 110
---|---
Mean | 28.78
Std Dev | 3.009

Entries | 150
---|---
Mean | 26.15
Std Dev | 4.116

Conclusions

• Knobs provide some improvements
• Still far from quantum limit
• Something missing from models?
Multi-Objective Genetic Algorithm

Problem Statement

• What if:
  • Competing criteria of optimal machine performance
  • In regime where model of machine responses is unreliable
• Needed: a model-agnostic search for optimal performance *trade-offs*
\[ xy \geq c^2, \ 1 \geq x \geq 0, \ 1 \geq y \geq 0 \]
The inequality $xy \geq c^2$, $1 \geq x \geq 0$, $1 \geq y \geq 0$ represents the shaded area in the Cartesian plane, indicating all points $(x, y)$ that satisfy these conditions.
\( xy \geq c^2, 1 \geq x \geq 0, 1 \geq y \geq 0 \)
$xy \geq c^2$, $1 \geq x \geq 0$, $1 \geq y \geq 0$
$xy \geq c^2$, $1 \geq x \geq 0$, $1 \geq y \geq 0$

neither $x$ nor $o$ dominates
$xy \geq c^2, \ 1 \geq x \geq 0, \ 1 \geq y \geq 0$
$xy \geq c^2, 1 \geq x \geq 0, 1 \geq y \geq 0$
genetic algorithm (spea2) toy example

Objective A

Objective B

parent population

How it works
genetic algorithm (spea2) toy example

Objective A

Objective B

offspring
genetic algorithm (spea2) toy example

survivors (parents of the next generation)
CESR simulation, noiseless
CESR simulation, noiseless

- y-axis: orbit, $\sum x^2$ (m$^2$)
- x-axis: vertical emittance (m)

Graph showing a relationship between orbit and vertical emittance, with a trend line indicating a decrease in orbit as the vertical emittance increases.
CESR simulation, noiseless

orbit, $\Sigma x^2$ (m$^2$)

vertical emittance (m)

$10^{-4}$

$10^{-5}$

$10^{-6}$

$10^{-12}$

$2 \times 10^{-12}$

$3 \times 10^{-12}$

$4 \times 10^{-12}$

$6 \times 10^{-12}$

$10^{-11}$
CESR simulation, noiseless

orbit, $\Sigma x^2$ (m$^2$)

vertical emittance (m)

- $10^{-4}$
- $10^{-5}$
- $10^{-6}$

$2 \times 10^{-12}$, $3 \times 10^{-12}$, $4 \times 10^{-12}$, $6 \times 10^{-12}$, $10^{-11}$
CESR simulation, noiseless

- Orbit, $\Sigma x^2$ (m$^2$)
- Vertical emittance (m)

Graph shows a downward trend with blue dots and a red line indicating a negative correlation.
CESR simulation, noiseless
CESR simulation, noisy without resampling

orbit, $\Sigma x^2$ (m$^2$)

vertical emittance (m)
CESR simulation, noisy without resampling

- **x-axis**: Vertical emittance (m)
- **y-axis**: Orbit, $\Sigma x^2$ (m$^2$)

The graph shows a scatter of data points with a trend line indicating a negative correlation. The data points are spread across a range of vertical emittance values, with a notable downward trend as the emittance decreases.
CESR simulation, noisy without resampling

- y-axis: orbit, $\Sigma x^2$ (m$^2$)
- x-axis: vertical emittance (m)

The graph shows a scatter plot with a red line indicating a linear trend between orbit and vertical emittance. The data points are spread across a log-log scale.
CESR simulation, noisy without resampling

- Orbit, $\Sigma x^2$ (m$^2$)
- Vertical emittance (m)

Graph showing a scatter plot with a trend line.
CESR simulation, noisy without resampling

orbit, $\Sigma x^2$ (m^2)

vertical emittance (m)
CESR simulation, noisy without resampling

- Orbit vs. vertical emittance (m²)
- Log-log scale
- Discrete data points and a trend line
- Axes labels: orbit, \( \Sigma x^2 \) (m²) vs. vertical emittance (m)
- Data range: orbit from \( 10^{-6} \) to \( 10^{-4} \), vertical emittance from \( 10^{-12} \) to \( 10^{-11} \)
CESR simulation, noisy without resampling

Orbit, $\Sigma x^2$ (m$^2$)

Vertical emittance (m)
CESR simulation, noisy without resampling

- orbit, \( \Sigma x^2 \) (m^2)
- vertical emittance (m)

Graph showing a scatter plot with data points and a red line indicating a trend.
CESR simulation, noisy without resampling

- Y-axis: Orbit, $\Sigma x^2 (m^2)$
- X-axis: Vertical emittance (m)

Graph showing a scatter plot with a linear trend line.
CESR simulation, noisy without resampling

- **orbit, \( \Sigma x^2 \ (m^2) \)**
- **vertical emittance (m)**

Graph showing a scatter plot with a trend line.
CESR simulation, noisy without resampling

The graph shows a scatter plot with points indicating the relationship between orbit, $\Sigma x^2$ (m$^2$), and vertical emittance (m). The red line represents a trend in the data.
CESR simulation, noisy with resampling

orbit, $\Sigma x^2$ (m$^2$)

vertical emittance (m)
CESR simulation, noisy with resampling

orbit, $\Sigma x^2$ (m$^2$)

vertical emittance (m)

- $10^{-4}$
- $10^{-5}$
- $10^{-6}$

- $2 \times 10^{-12}$
- $3 \times 10^{-12}$
- $4 \times 10^{-12}$
- $6 \times 10^{-12}$
- $10^{-11}$
CESR simulation, noisy with resampling

orbit, $\Sigma x^2$ (m$^2$) vs. vertical emittance (m)
CESR simulation, noisy with resampling

Orbit, $\Sigma x^2$ (m$^2$) vs. vertical emittance (m).

The graph shows a scatter plot with a red line indicating a trend. The x-axis represents the vertical emittance (m), ranging from $10^{-12}$ to $10^{-11}$, and the y-axis represents the orbit, $\Sigma x^2$ (m$^2$), ranging from $10^{-6}$ to $10^{-4}$. The data points form a pattern suggesting a correlation between the orbit and the vertical emittance.
CESR simulation, noisy with resampling

orbit, $\Sigma x^2$ (m$^2$)

vertical emittance (m)

$10^{-4}$

$10^{-5}$

$10^{-6}$

$10^{-12}$

$2 \times 10^{-12}$

$3 \times 10^{-12}$

$4 \times 10^{-12}$

$6 \times 10^{-12}$

$10^{-11}$
• Needed: a model-agnostic search for optimal performance *trade-offs*

• We tested an elitist genetic algorithm with re-sampling on bdad simulations of CESR

• Solution set shows randomness but converges in statistics

• Numerical evidence that power-law fit to solution set is an unbiased estimate of trade-off front
Preliminary Results
Final Thoughts

• Any real-life online optimization *metaheuristic* is likely to be a combination of model-cognizant and model-agnostic parts;
• Machine safety needs to “filter” trial solutions preventing them from adopting forbidden states;
• Noise handling and maximizing throughput are always key issues;
• CESR is an ideal platform to deploy new kinds of online optimization strategies, including AI and stochastic algorithms.