Cross-entropy Method In Structural Optimization with Dynamic Constraints

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CROSS-ENTROPY METHOD IN STRUCTURAL OPTIMIZATION WITH DYNAMIC CONSTRAINTS

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INTRODUCTION

→ Structural optimization has the typical objectives as mass reduction (weight), change natural frequencies (avoid resonance), reduce internal stress and REDUCE COST.

→ Gradient based methods are not possible in some cases.

→ Metaheuristics may be an alternative, but may have high computational cost or may be prohibitive.

→ Cross-entropy method (CE) has been used successful in combinatorial optimization and estimation of rare events in the last two decades

→ Due to complex geometric configurations, structural optimization can be extremely non-linear, requiring the use of very efficient optimization algorithms.

OBJECTIVE

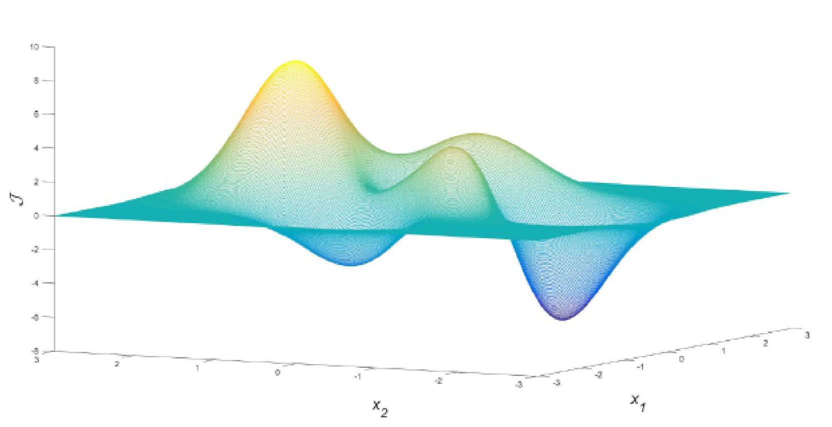
→ Propose a Cross-Entropy framework for structural optimization and investigate its accuracy and efficiency.

→ Compare optimal values found by the CE with other results obtained by Sequential quadratic programming (SQP) and Genetic algorithm (GA).

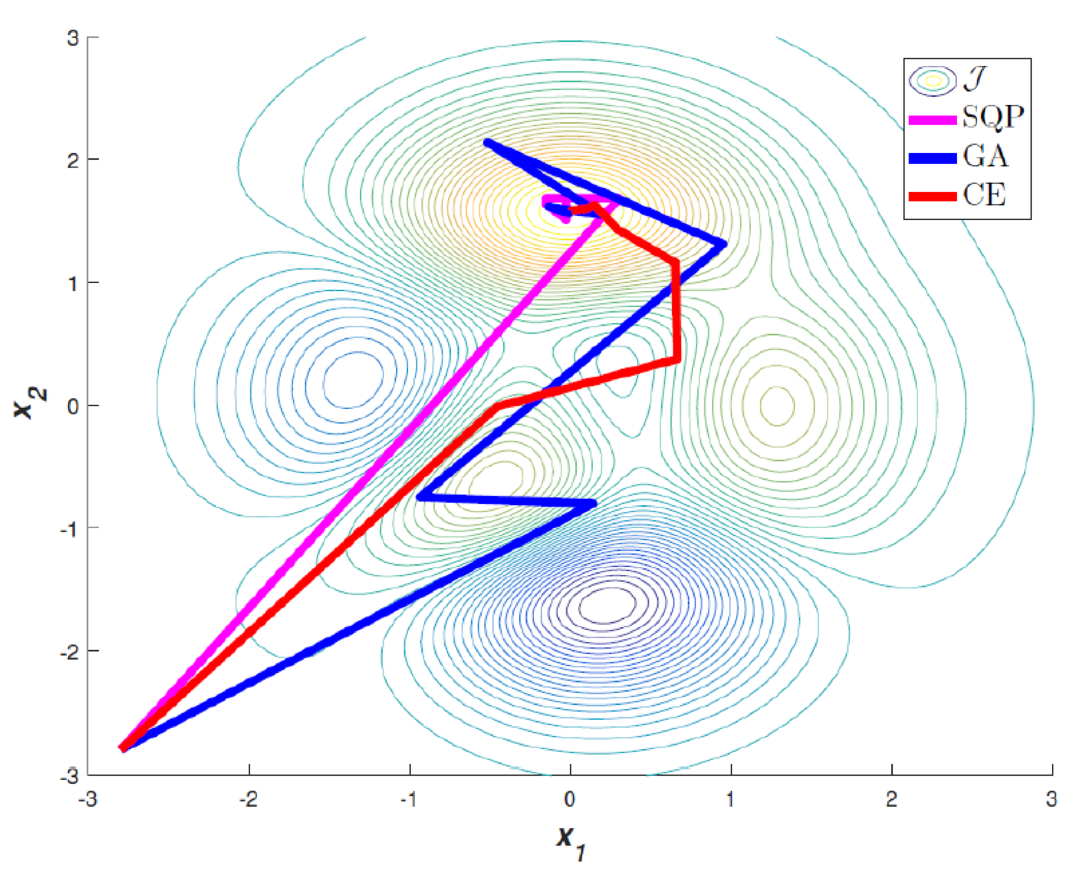
BENCHMARK TEST

FIGURE 1 – Benchmark test.

$$\mathcal{J}(x_1,x_2) = 3(1-x_1)^2\, e^{-x_1^2-(x_2+1)^2} - 10\left(\frac{x_1}{5} - x_1^3 - x_2^5\right) e^{-x_1^2-x_2^2} - \frac{1}{3}\, e^{-(x_1+1)^2-x_2^2}$$

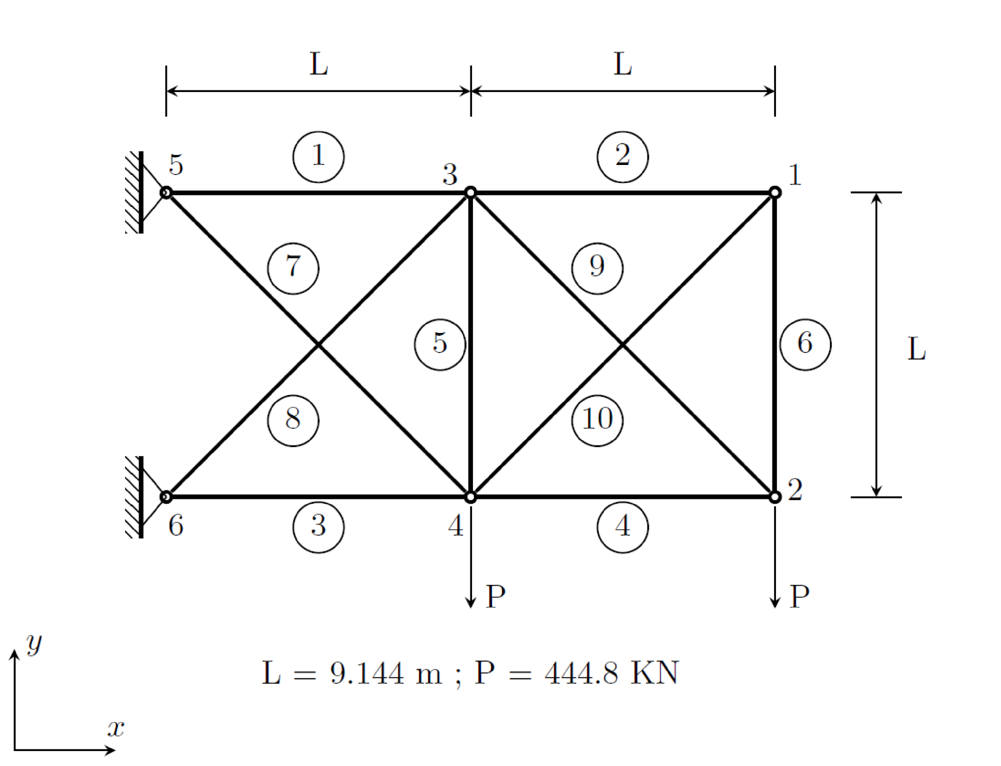


Method	$\mathcal{J}$	x_1	x_2	Func. Eval.
SQP	8.1	0	1.58	33
GA	8.1	0	1.58	1525
CE	8.1	0	1.58	625



STRUCTURAL OPTIMIZATION

FIGURE 2 – Structural optimization.



Find

$\min_x m = \sum_{e=1}^{10} \rho A_e L_e, \qquad x = \{A_e\}$,
(mass of structure)

where

$65.4\ mm^2 \leq A_e \leq 5000\ mm^2$,
(design limits)

$m_{ad} = 454\ kg$,
(additional mass)

subject to

$\omega_1 \geq 7\ Hz$, $\omega_2 \geq 15\ Hz$ and $\omega_3 \geq 20\ Hz$.
(natural frequencies)

$[\mathbf{K}]\phi = \omega^2[\mathbf{M}]\phi$.
(eigenvalue problem)

Source: HAFTKA; GÜRDAL , 1992

CE ALGORITHM

FIGURE 3 – CE algorithm.

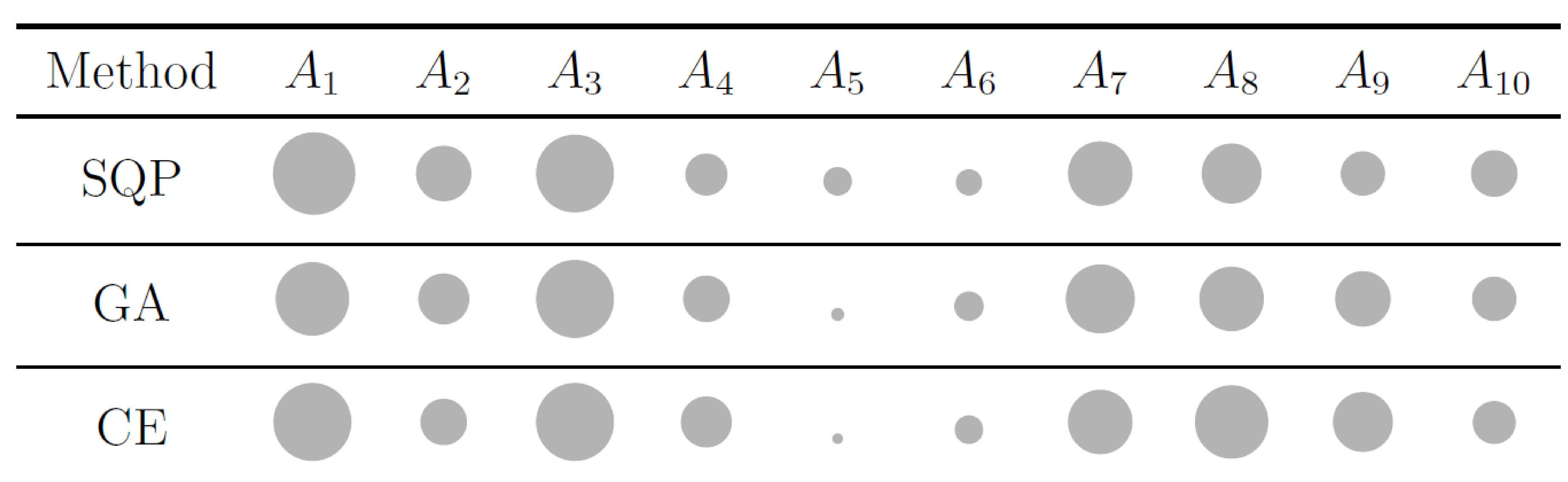
1. Define N^s, N^e, ti_{max}, $ti = 0$, $f(\cdot, \mathbf{v})$ and $\widehat{\mathbf{v}}_0$
2. Update level $ti = ti + 1$
3. Generate $\mathbf{X}_1, \cdots, \mathbf{X}_N$ (iid) samples from $f(\cdot, \widehat{\mathbf{v}}_{ti-1})$
4. Evaluate objective function $\mathcal{J}(\mathbf{X}_n)$ at samples $\mathbf{X}_1, \cdots, \mathbf{X}_N$ and sort the results $\mathcal{J}_{(1)} \leq \cdots \leq \mathcal{J}_{(N)}$
5. Update estimators $\widehat{\gamma}_{ti}$ and $\widehat{\mathbf{v}}_{ti}$
6. Repeat ② — ⑤ while stopping criterion is not met

RESULTS

TABLE 1 – Comparison between the results obtained with different techniques optimization the area of each bar.

METHOD	MASS	FUNC. EVAL.
SQP	530 kg	313
GA	529 kg	9836
CE	535 kg	4800

TABLE 2 – Illustration of the areas obtained by the three optimization methods considering natural frequencies constraint.



CONCLUSIONS

→ Only global search algorithms should be used to obtain optimal solutions for these optimization problems with dynamic constraints.

→ In general, the SQP obtains better results than the GA and the CE. However, in this case, the metaheuristic, GA, obtain better results than those of SQP, which is a gradient-based optimization method, and CE has a satisfactory result.

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