

PHYSICS-DATA STRUCTURAL OPTIMIZATION: FROM LATENT SPACES TO MEMBER COMPOSITION

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ABSTRACT

Designing high-performing structural systems requires balancing strict mechanical requirements with practical constraints related to fabrication, transportation, and construction. This talk presents two machine learning-based frameworks for scalable, data-driven structural optimization. While grounded in learned representations and structured decision-making, both approaches echo classical computational mechanics techniques – namely, model order reduction and domain decomposition.

The first method targets real-time topology optimization through a two-stage surrogate modeling pipeline [1]. Inspired by reduced-order modeling of parametrized differential problems, it projects high-dimensional optimal topologies onto a low-dimensional latent manifold using a deep autoencoder. A neural surrogate maps design parameters to this latent space, enabling the decoder to reconstruct both topology and stress fields in real time, without the need for iterative solvers. Here, optimization is performed offline using a dataset of precomputed solutions, trading costly training for virtually instantaneous inference.

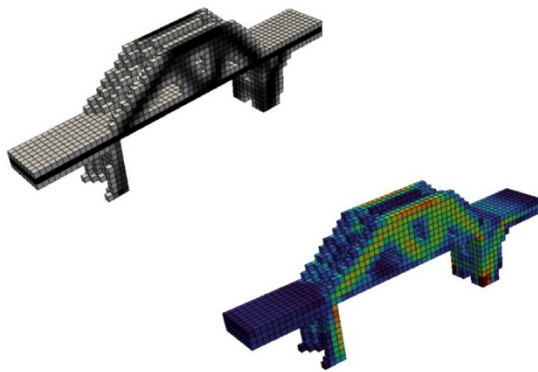
The second framework addresses truss optimization via a generative formulation based on grammar-constrained Markov decision processes [2]. In this setting, optimization is intertwined with learning: the design policy improves while sequentially assembling truss members under grammar rules that encode engineering feasibility. These constraints decompose the design space into meaningful subregions, enabling efficient exploration of design trajectories. This strategy mirrors domain decomposition in spirit, as the final structure is assembled from interpretable base components, analogous to subdomain solutions.

These methods demonstrate how integrating engineering principles with modern machine learning yields efficient, high-quality structural designs. We showcase their computational advantages and robustness through several examples, particularly in progressive construction scenarios.

REFERENCES

- [1] G. Garayalde, M. Torzoni, M. Bruggi, A. Corigliano. Real-time topology optimization via learnable mappings, *International Journal for Numerical Methods in Engineering* 125(15):e7502, 2024.
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Real-time topology optimization via learnable mappings



Progressive truss design with Monte Carlo tree search

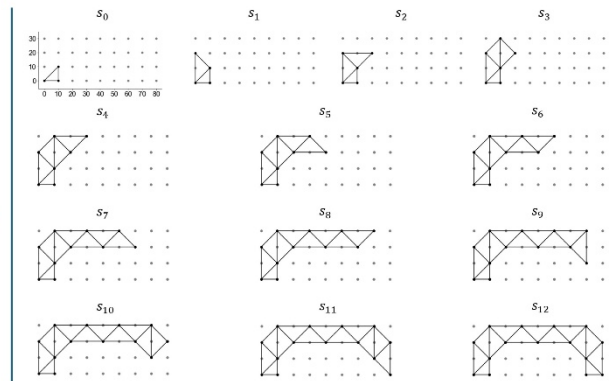


Figure 1: Exemplary results for bridge-like structures obtained using (left) real-time topology optimization via learnable mappings, and (right) progressive truss design with Monte Carlo tree search.