FY24 Topic Areas Research and Technology Development (TRTD)

A super-resolution Machine Learning approach to Topology Optimization to enable rapid generation of low mass designs

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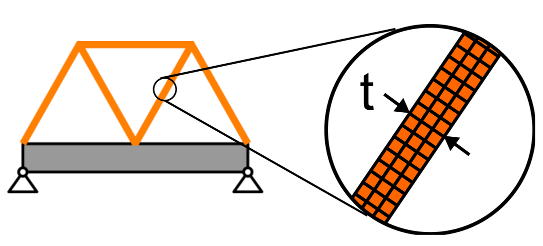
Strategic Focus Area: Supervised and Unsupervised Learning

Background

Topology Optimization (TO) is a physics-based computational design tool with the ability to **generate structural designs often 15-20% lighter** than conventional design approaches. The thin geometries required for many aerospace structures require high resolution finite element meshes to yield quality (TO) designs, resulting in **high computational power needs coupled with long solution times** .

TO requires 3 elements through the minimum feature size of interest.



JPL Ti and Al 3D print build volume
250x250x325 mm

Approach

- Learn the mapping between low and high resolution TO design domains.
- Maintain fine-scale information within coarse-scale optimizations by detuning the optimization to generate fuzzy geometries.
- Build upon existing image-based Super Resolution methodologies.

Results

- Developed an in-house TO framework in both 2D and 3D capable of designing structures with varying load conditions and mass targets.
- A range of ML models were developed, including Super Resolution Residual U-Nets, a General Adversarial Network (SRGAN), and a Transformer (SWIN).
- The SRGAN demonstrated the highest performance, but further work is required (especially for 3D design).
- Demonstrated 12x faster 2D design generation and 70x faster 3D design generation (hours to minutes)

Objective

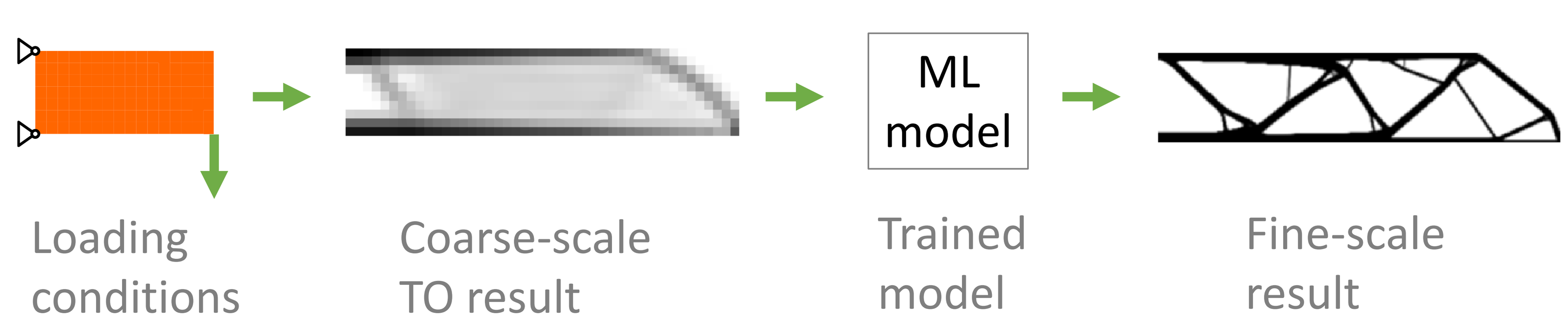
Develop a system that leverages rapid coarse-scale Topology Optimization (TO) designs to seed robust high resolution TO designs through **Machine Learning** (ML), enabling **10x faster design generation** than high resolution TO alone while maintaining comparable performance.

State-of-the-Art

For design volumes consistent with JPL metal 3D printers, TO computational costs often become limiting at small feature sizes.

Feature size (mm)	Number of elements	Computer required	Design time
1	548,437,500	Cluster	Weeks to months
3	20,312,500	High-end PC	Days to weeks
6	2,539,000	Standard PC	Hours to a days
12	317,382	Laptop	Minutes to hours

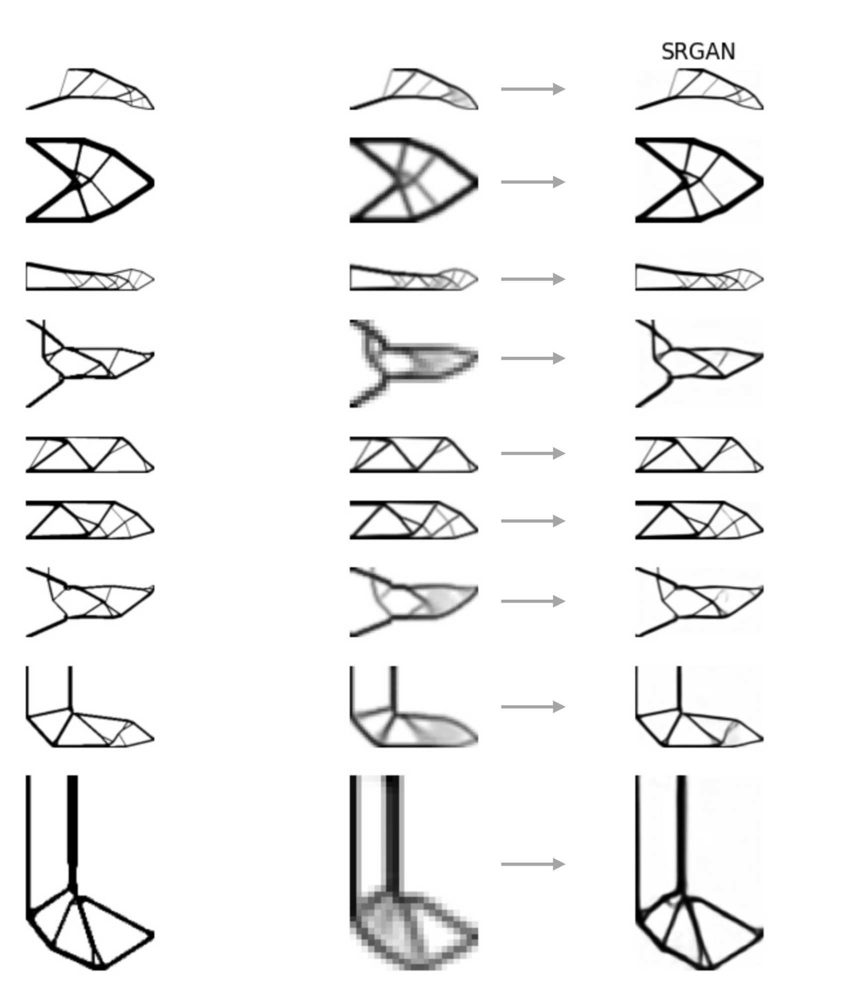
Developed framework



2D Design Results

Conventional | 12x faster ML Framework

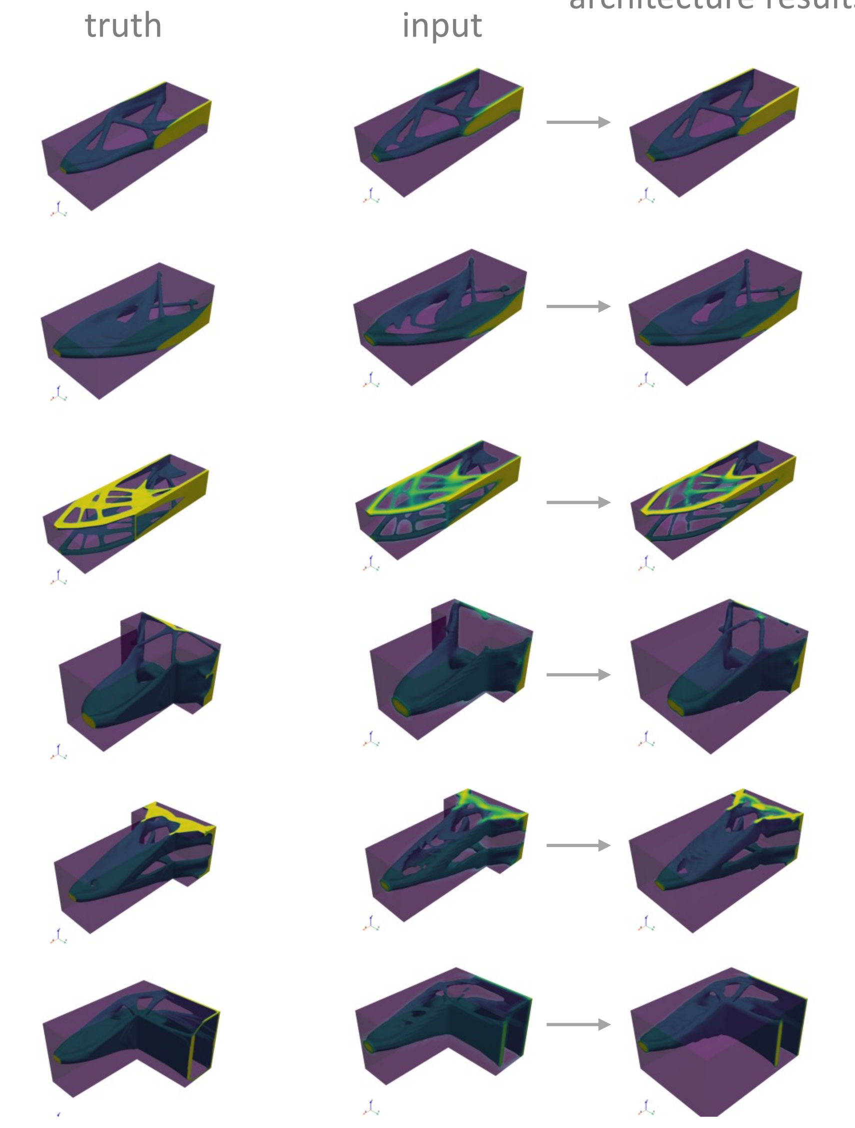
Fine-scale ground truth | Coarse-scale ML model input | Different ML model architecture results



3D Design Results

Conventional | 70x faster ML Framework

Fine-scale ground truth | Coarse-scale ML model input | ML model architecture results



National Aeronautics and Space Administration

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California Institute of Technology
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www.nasa.gov

RPD-006 Clearance Number: CL#24-5169

Publications:

H. S. Venkataram, V. Constantinou, D. Wrench, A. Forouzani and R. Watkins, "Super-Resolution Based Topology Optimization for Rapid Generation of Low Mass Structural Designs," *2024 IEEE Aerospace Conference*, Big Sky, MT, USA, 2024, pp. 1-10
doi: 10.1109/AERO58975.2024.10521001.

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