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N-body Adaptive Optimization of Lattice Towers

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Abstract

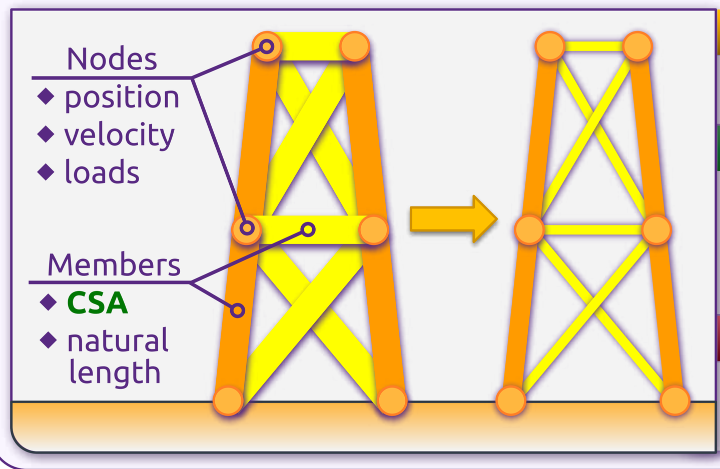
In the US alone, transmission towers number in the tens of millions; most are lattice-based, comprising a framework of beams connected at nodes. At tens- to hundreds of thousands of dollars each, primarily in material costs, they are a sizable expense to taxpayers and transmission companies.

The dilemma central to their optimization is that a beam's cross-sectional area is proportional to both its strength *and* cost, i.e. a thicker beam, while able to support a given load with less strain, will cost more and weigh more heavily on the beams supporting it.

By varying the cross-section of each beam, we want to make towers as light and inexpensive as possible without sacrificing their structural integrity. Known as truss-sizing optimization, this problem is differential in nature and heavily dependent on tower geometry, lending it to a computational approach.

Drawing inspiration from the atrophy and hypertrophy of muscles, we develop and evaluate an optimization algorithm that adaptively resizes beams based on their stress – a process that produces rapid results and allows the application of both static and dynamic loads, setting it apart from popular algorithms in this intensely studied field.

Objective & Constraints

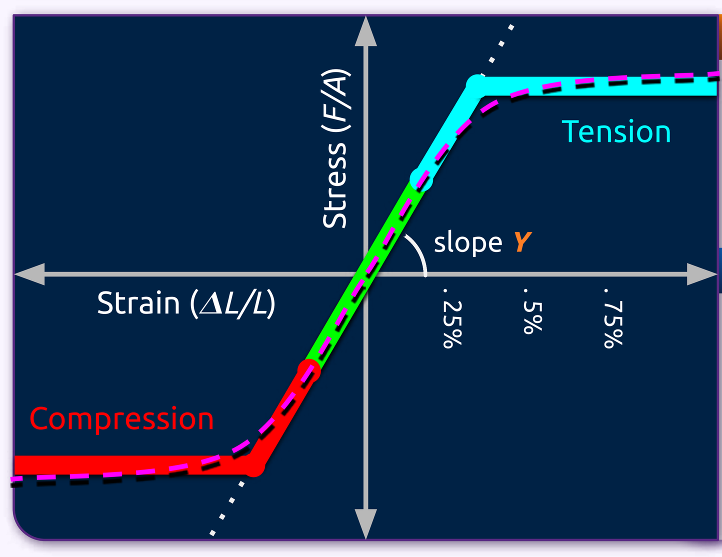


Objective
Make a given lattice tower as light as possible.

Variable
Each member has a cross-sectional area (CSA) that determines its strength and weight. The CSA of each member or member group is varied.

Constraints
- Maximum strain
- Allowable CSA range
- Maximum node displacement

Stress, Strain & Loads



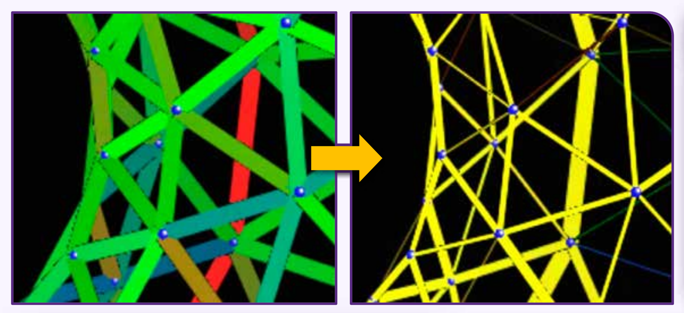
Material stress-strain curve, true (magenta) & simulated (tricolor)

Force Curve
A beam behaves like a spring, having a natural length and a strength dependent on CSA, Young's modulus Y, and **strain** (relative change in length):
$$F = -\text{strain} \cdot Y \cdot \text{CSA}$$

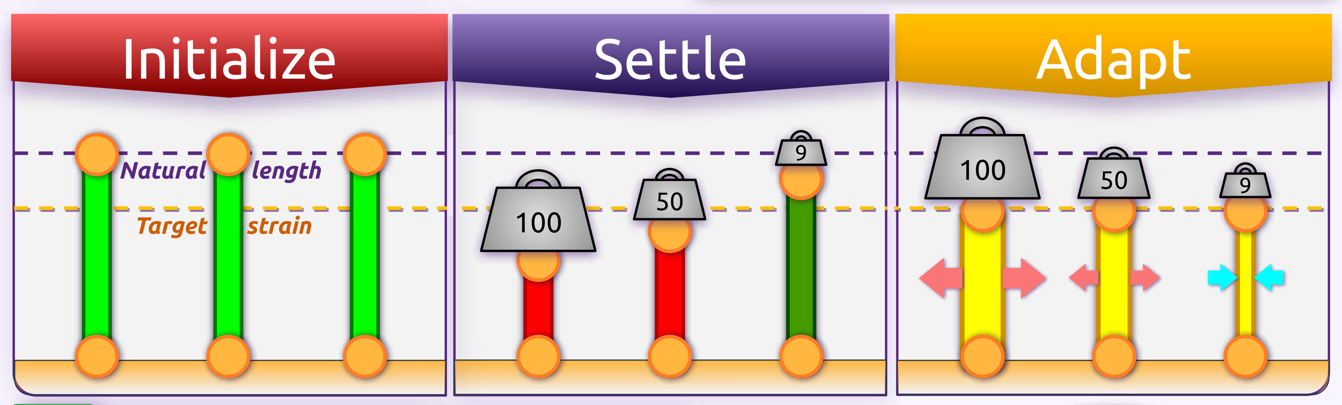
Applied Loads
In our simulation, lattice towers are subjected to various static and dynamic loads:
- Dead load (self-weight, power lines, etc.)
- Live load (occupants, temporary loads)
- Wind, seismic, ice, etc. loads

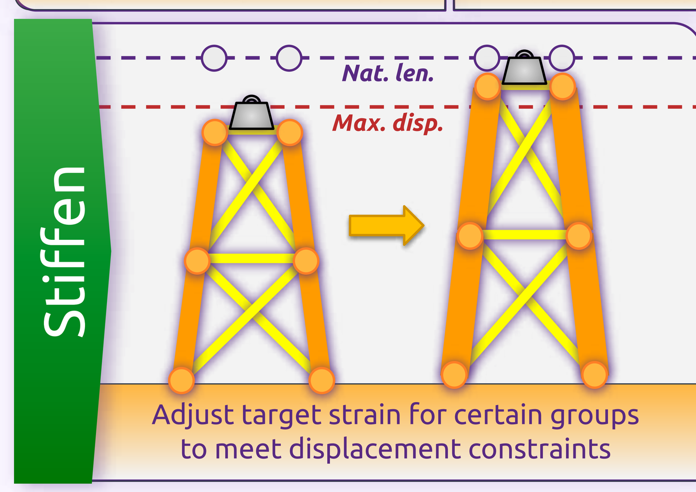
Loads are applied at nodes, e.g. the weight of a member is divided evenly between its nodes.

Adaptive Algorithm

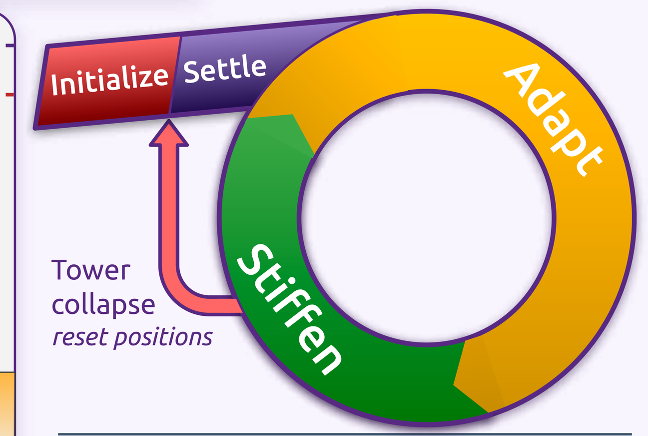


Rules
- Each member has a *target strain σ*
- If strain < σ, member *atrophies*
- If strain > σ, member *grows*



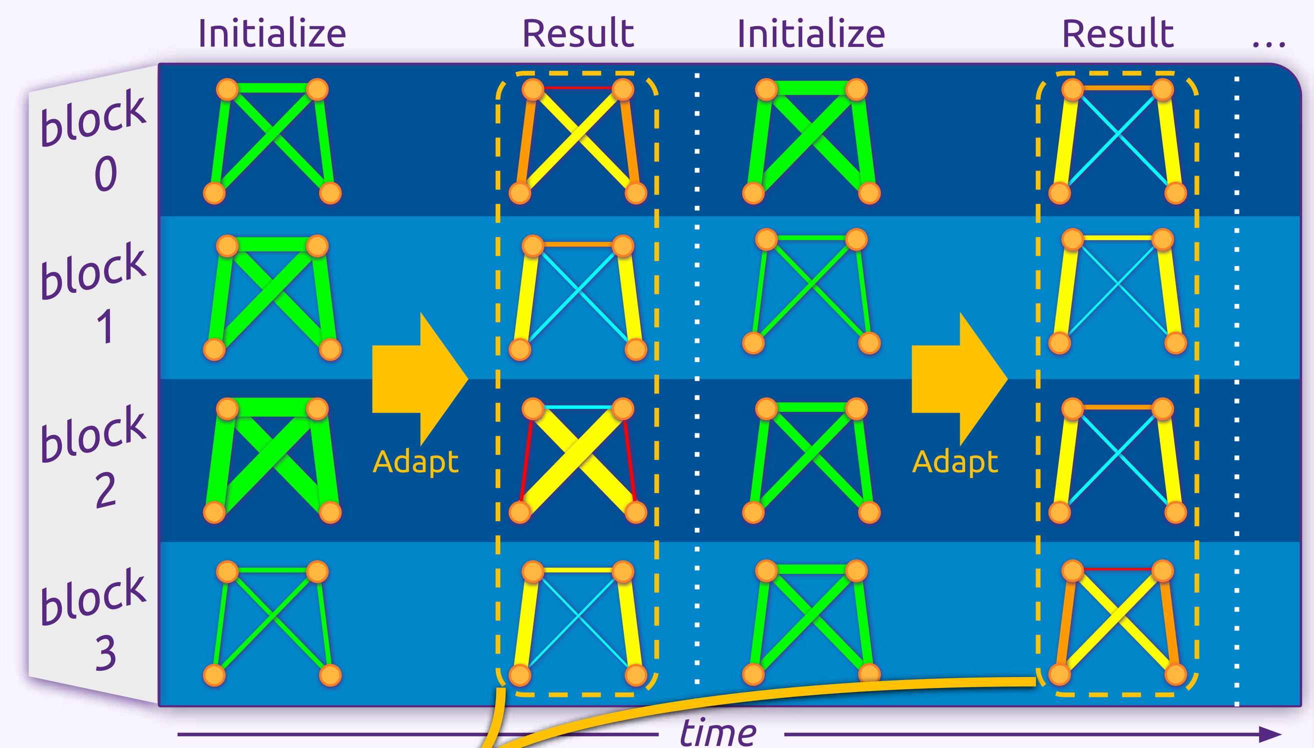


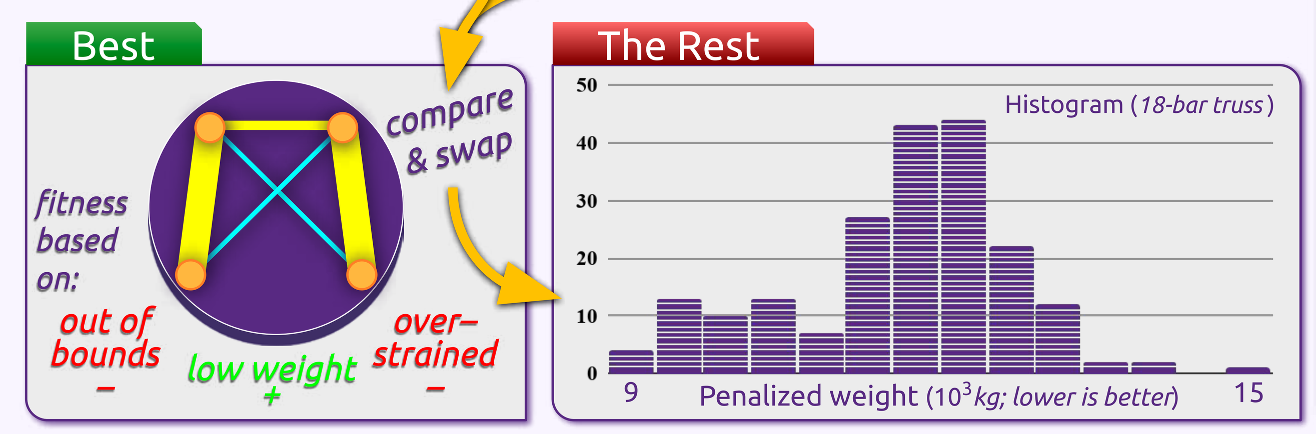
Adjust target strain for certain groups to meet displacement constraints

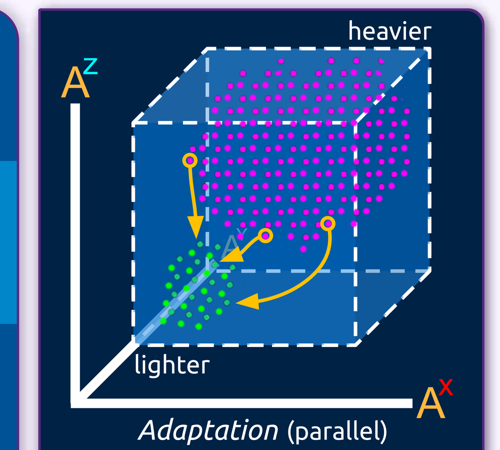


Adaptation cycle

Parallel Approach

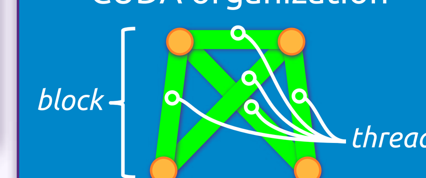






Adaptation (parallel)

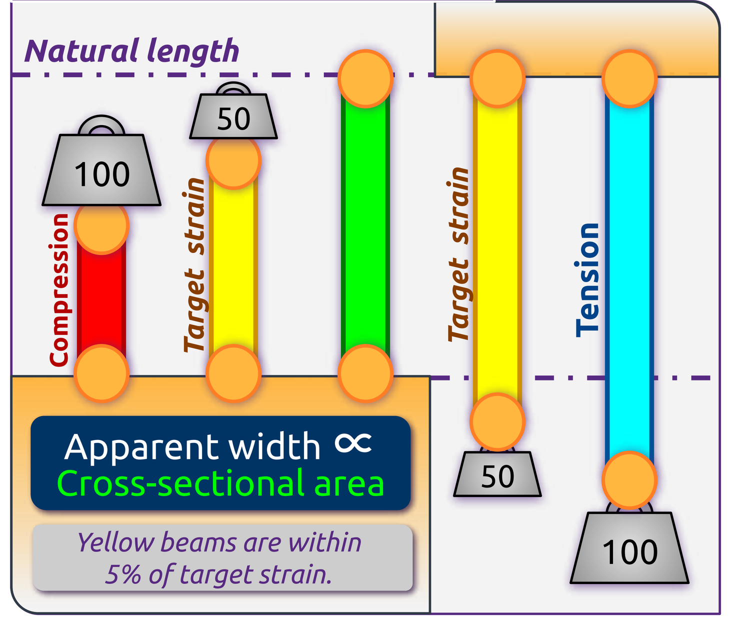
CUDA organization



- Many (1,000,000+) blocks
- Several consec. runs per block
- **M** (members) threads per block
- First **N** (nodes) control nodes
- First **G** (groups) control groups

Parameter variation
- Initial CSA
- CSA distribution (unif/exp/rand)
- Adaptation rate
- Time-variant strain/disp. limits

Strain Legend



Apparent width ∝ Cross-sectional area

Yellow beams are within 5% of target strain.

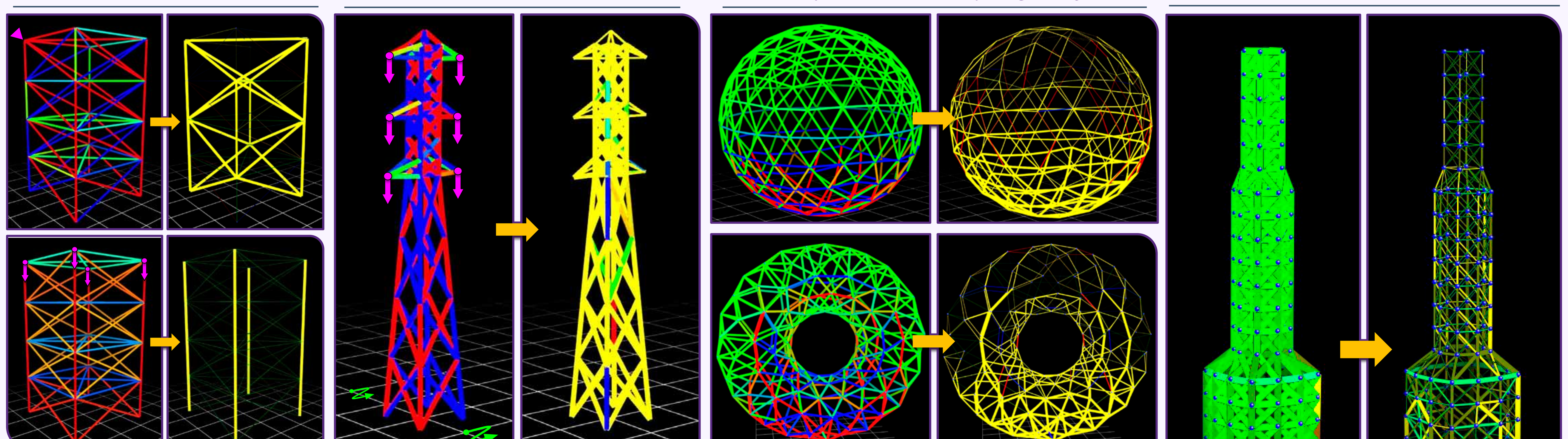
Hardware

Nvidia GeForce GTX Titan
Intel i7 950

GPU vs. CPU
On single-run tests, GPU outperforms CPU by ~20×.
The GPU can run 1,048,576+ adaptations at once.
Speedup over CPU roughly 20 million ×.
(5-10 s/run; simultaneous runs do not affect performance)

Results

72-bar truss, 2 load configurations · *Small tower, cable and seismic loads.* · *Icosphere and torus, self-weight only* · *26-story tower, asymmetric load*

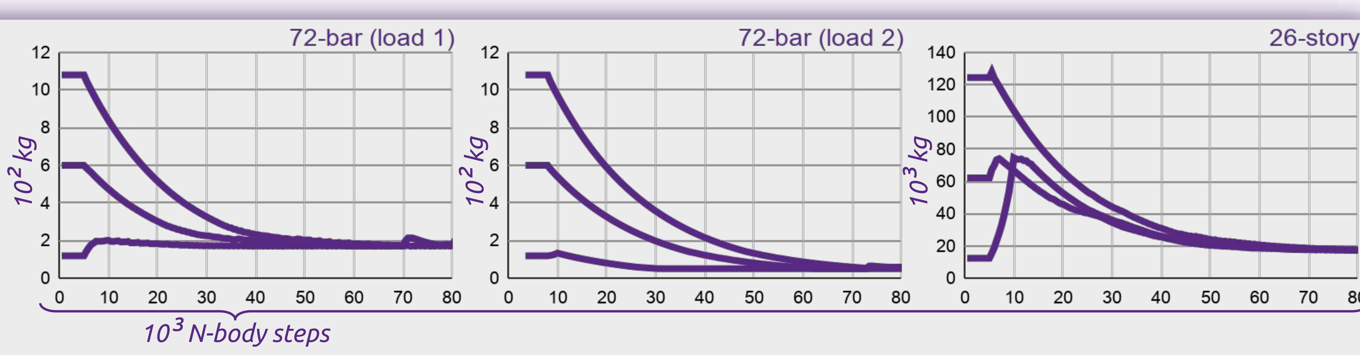


Convergence

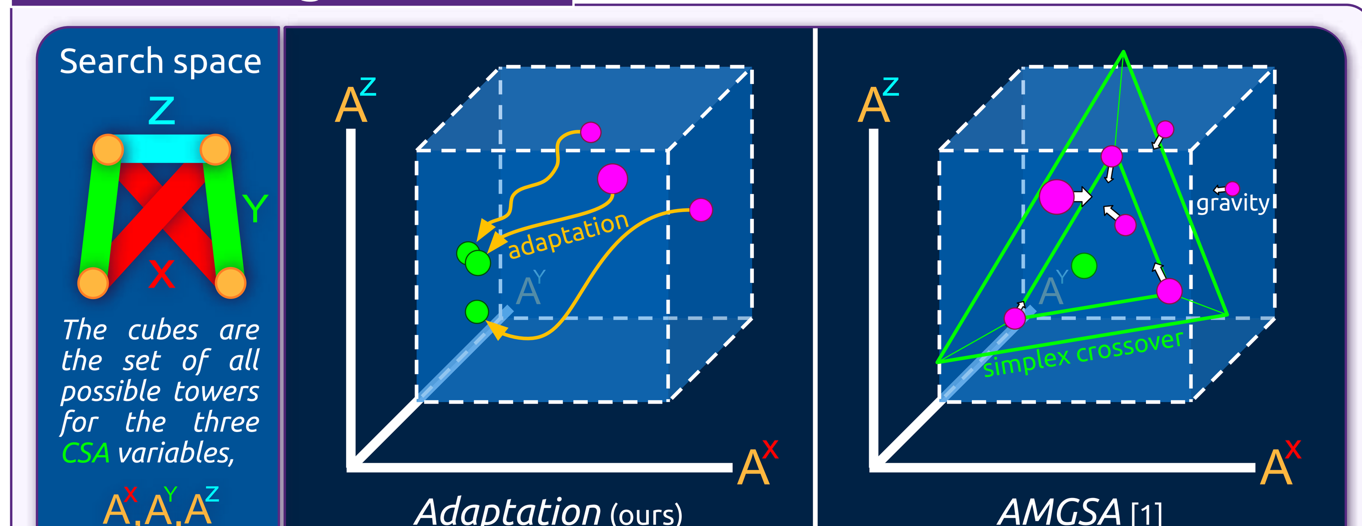
Initial CSA generally has little impact on convergence.

In the last figure, however, the lowest initial CSA caused a collapse, prompting sudden growth.

Simulation videos



Search Algorithms



	Adaptation (ours)	AMGSA [1]
Inspiration	Muscle growth and atrophy	Gravitation, Genetics
Physics model	N-body (numeric integration)	Matrix algebra
Search behavior	Gradual refinement	Attraction, breeding, mutation
Advantage	Dynamic loads, rapid convergence, GPU acceleration	Matrix efficiency, deep mathematical foundation idealistic physics

References:
[1] Khatibinia, Mohsen & Yazdani, Hessam. (2017, July). Accelerated multi-gravitational search algorithm for size optimization of truss structures. In *Swarm and Evolutionary Computation.*

Acknowledgements:
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