# NASA Tensegrity Robotics Toolkit

## Structure Building & Learning Framework Extensions

## What is Tensegrity?

Tensegrity is a structural principle where isolated rods are held together by a set of tensioned strings. Actuators are used to contract strings and control movement. Tensegrity structures are both strong and flexible due to the dynamic interplay between tension and compression forces. Tensegrity has applications in architecture, biology, and robotics (Figures 1 to 4).

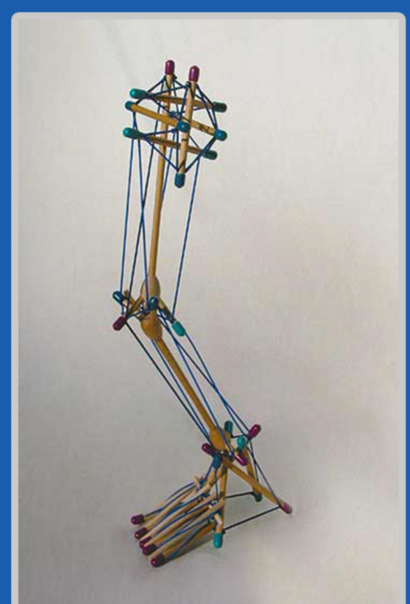


Figure 1. Tensegrity leg model by Tom Flemons.

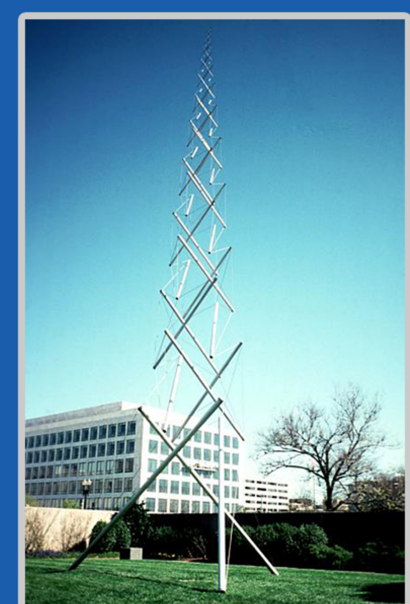


Figure 2. Needle Tower by Kenneth Snelson.

## NASA Tensegrity Robotics Toolkit

The NASA Tensegrity Robotics Toolkit (NTRT) is an open-source software suite designed to model, simulate, and control tensegrity structures in a 3D environment. One of the goals of NTRT is to discover structures that have the potential to be used to create exploratory robots (Figures 3 & 4). The unique structural qualities of tensegrities enable them to absorb impacts and be deployed from compact spaces.

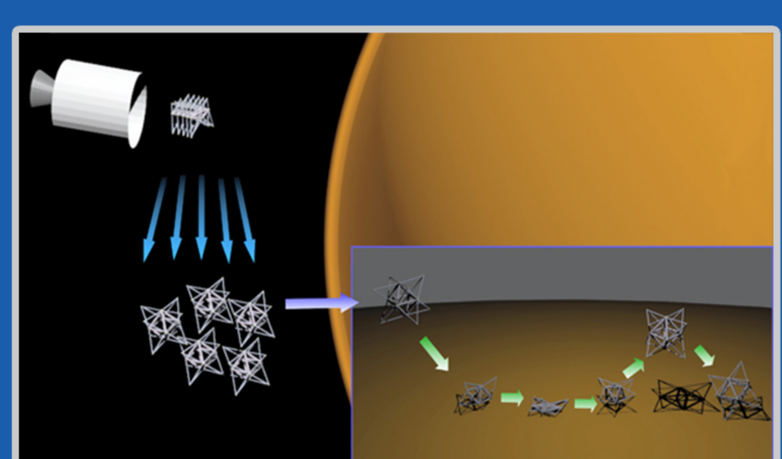


Figure 3. Concept rendering showing deployment of SuperBall Bots.

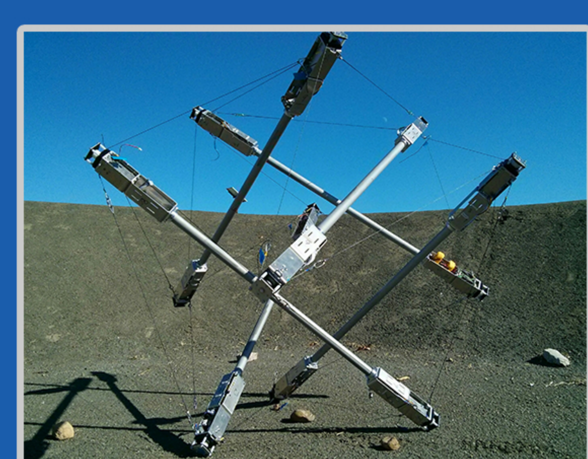
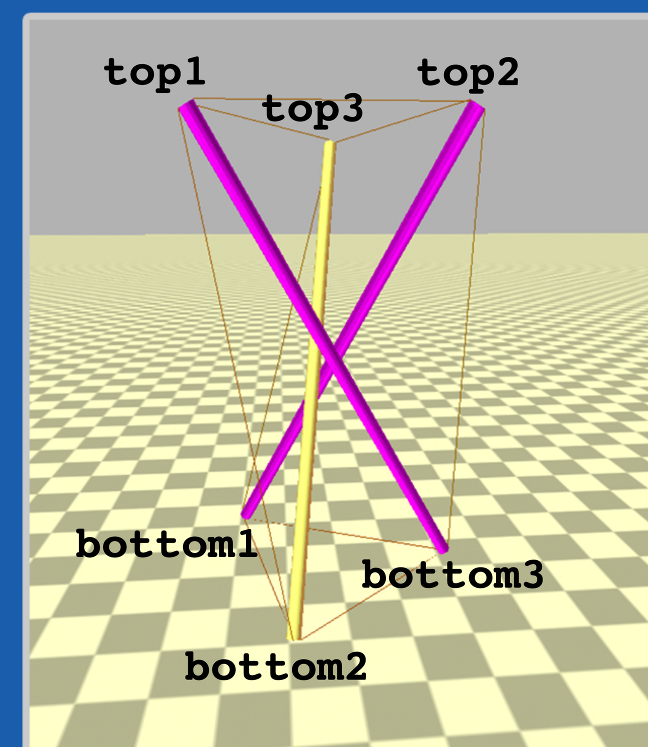


Figure 4. Early prototype of actuated SuperBall Bot.

## Structure Building

Prior to our contributions to NTRT, the method for building structures involved writing C++ code and interfacing with NTRT's internal libraries. Simple modifications to a structure were non-trivial and required recompiling source code. To make NTRT accessible to a wider audience including non-technical users, a new approach to defining structures was needed.




```
nodes:
  bottom1: [-2.5, 0, 0]
  bottom2: [2.5, 0, 0]
  bottom3: [0, 0, 5]
  top1: [-2.5, 10, 0]
  top2: [2.5, 10, 0]
  top3: [0, 10, 5]

pair_groups:
  prism_rods:
    - ["bottom1", "top2"]
    - ["bottom2", "top3"]
    - ["bottom3", "top1"]
```

Figure 5. A 3-Prism modeled in NTRT (left). YAML representation of the nodes and rods (right).

The new specification (Figure 5) makes it easy to build complex tensegrities made up of multiple substructures (Figure 6). Structures are combined by specifying connections between nodes and edges. The system automatically performs coordinate transformations to properly connect substructures.

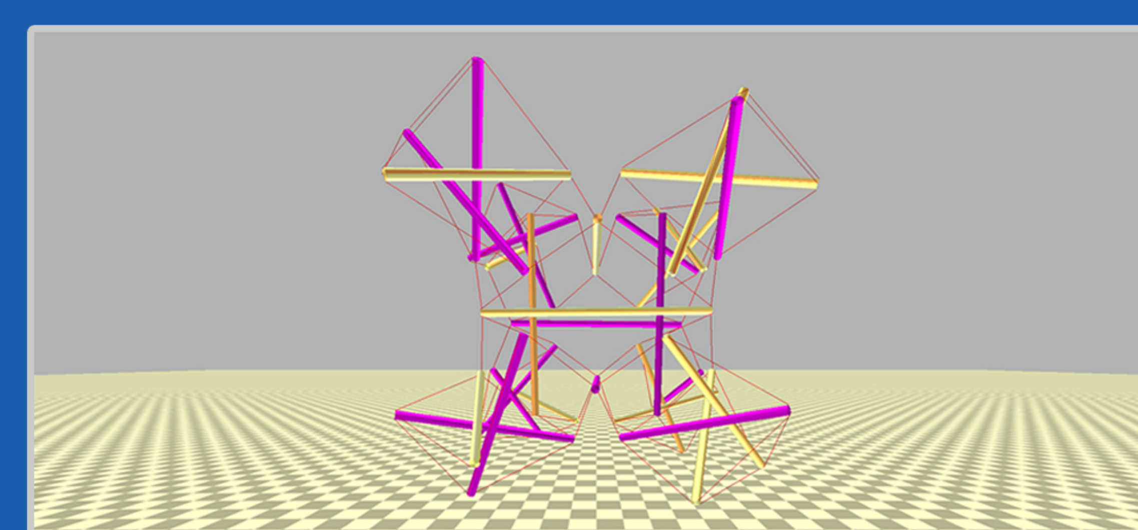


Figure 6. Spider structure made by attaching eight 3-Prisms to a SuperBall using node-to-edge connections.

## Learning Framework

NTRT includes a machine-learning framework to discover actuation patterns for structure movement. Early research [1] focused on tensegrity spines using central pattern generators (Figure 7). A combination of two-step Monte Carlo and genetic algorithms was used to discover better actuation patterns for these spines (Figure 8). Learning was performed over different types of terrain including flat, hilled, and cratered surfaces. The applied fitness function was distance traveled over 60 seconds.

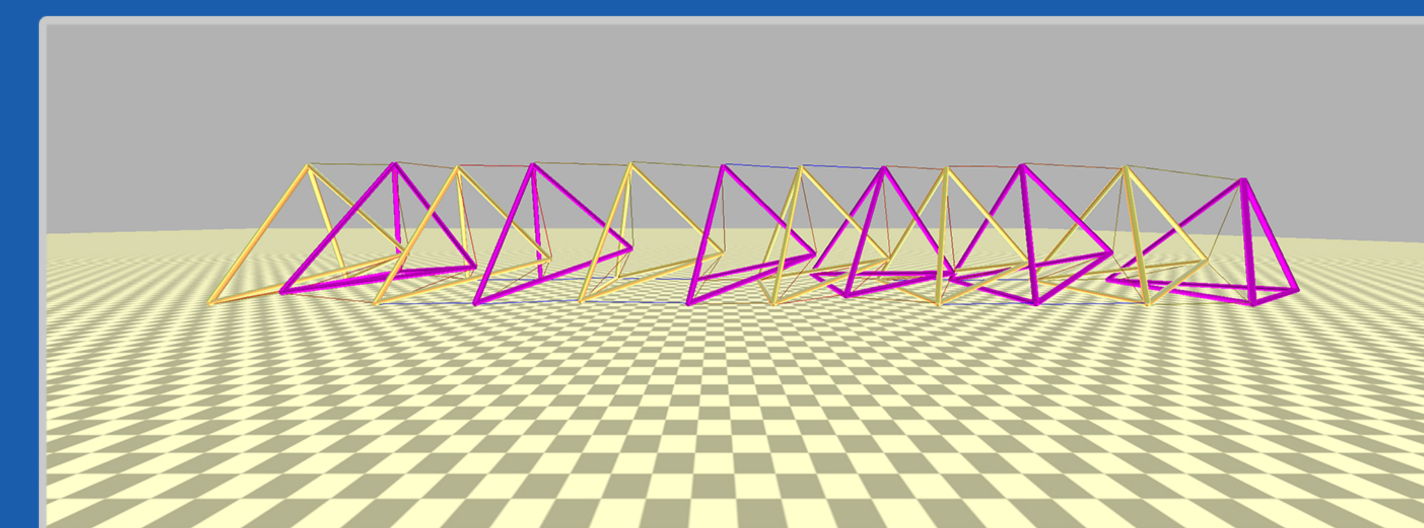


Figure 7. A 12-segment tetrahedron spine by Dr. Brian Mirletz.

Our new learning framework is no longer limited to spine-like structures and enables learning to alter physical properties, such as rod radius or string tension levels. Parameters of the learning framework provide convenient control over the fitness function, learning algorithms, and evolution methods.

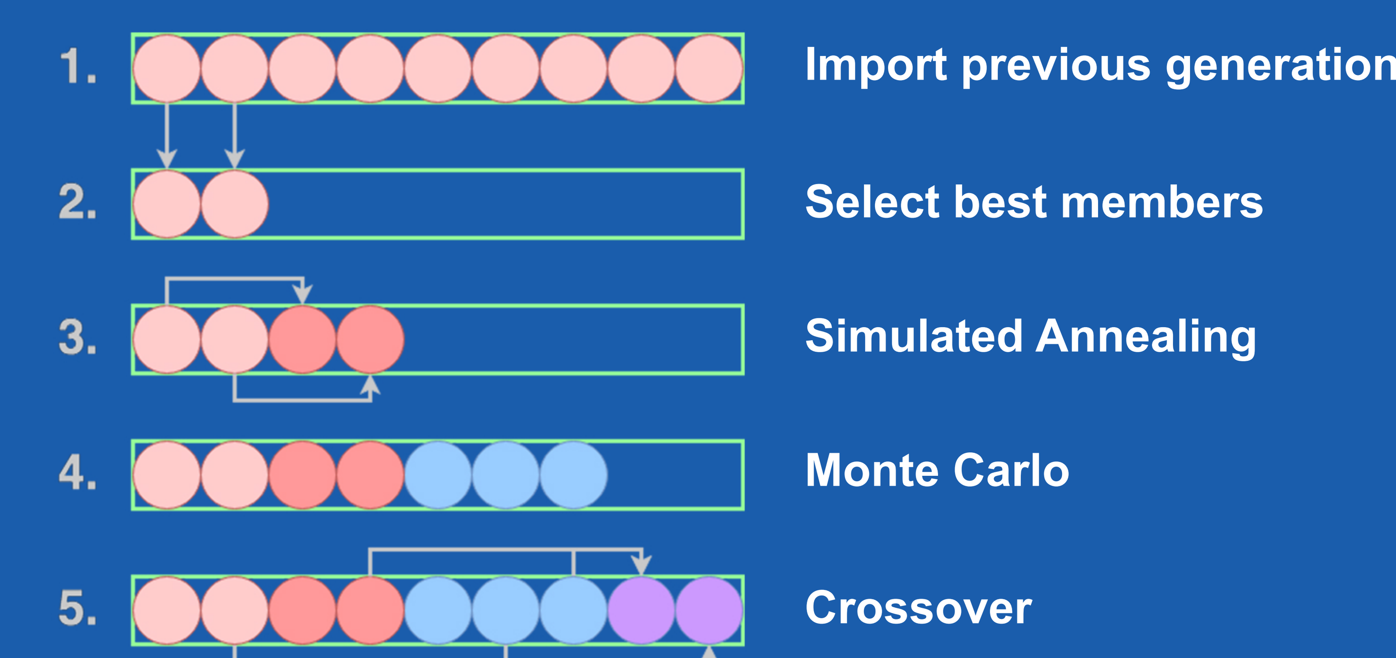



Figure 8. A depiction of the learning algorithm implemented in NTRT.

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**References**

[1] Mirletz, Brian T., et al. "Design and control of modular spine-like tensegrity structures." The 6th World Conference of the International Association for Structural Control and Monitoring (6WCSCM). 2014.
http://ti.arc.nasa.gov/tech/asr/intelligent-robotics/tensegrity/
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