A Comprehensive Computational Framework to Evaluate Grasp Quality of Tendon-Driven Hands with Arbitrary Topology

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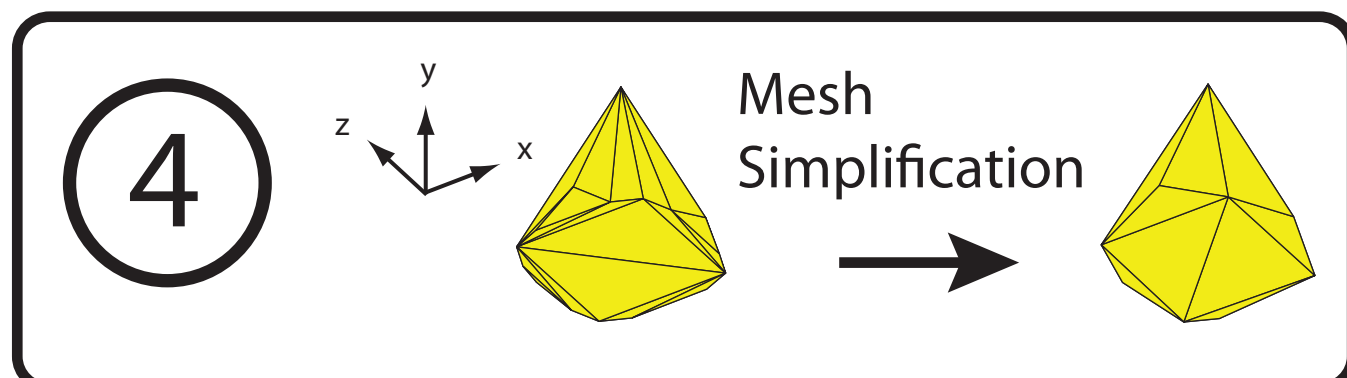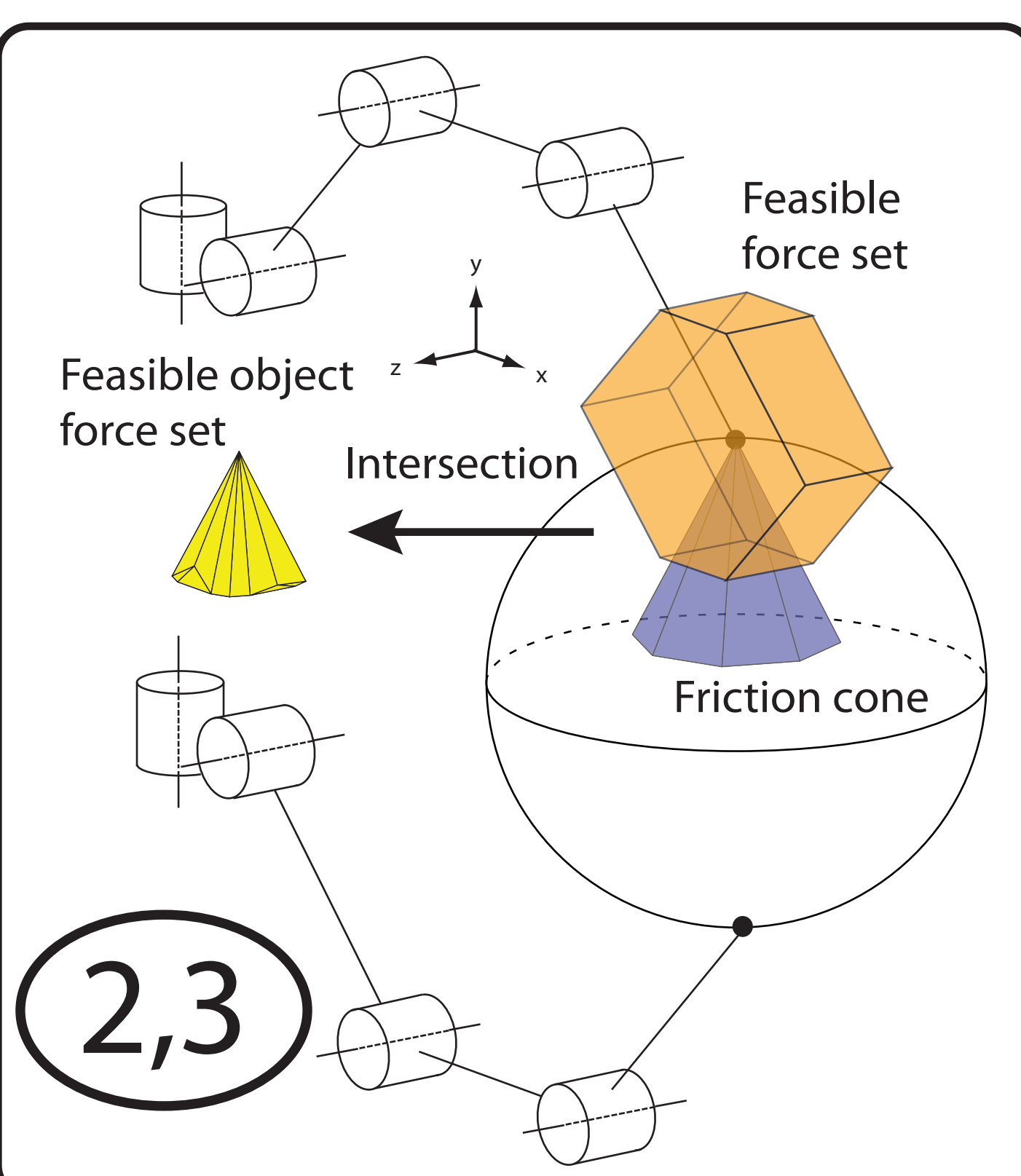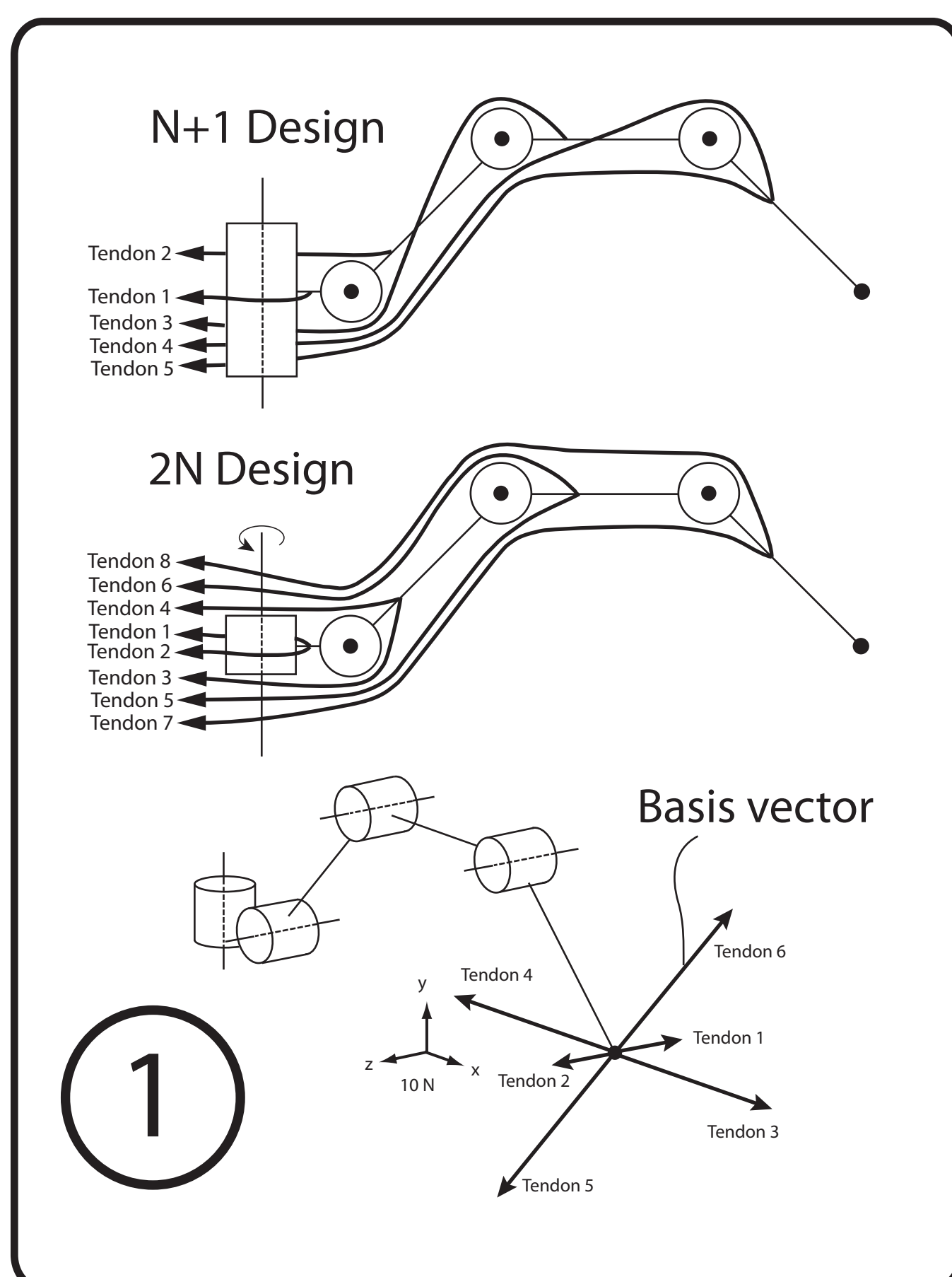
Introduction

• Biologically-inspired tendon-driven robotic hands have many advantages over torque-driven hands [1,2].

• We have developed a novel comprehensive computational framework for evaluating grasp capabilities of these hands.

• *This breakthrough now enables the systematic design, evaluation, and optimization of complex tendon-driven systems.*
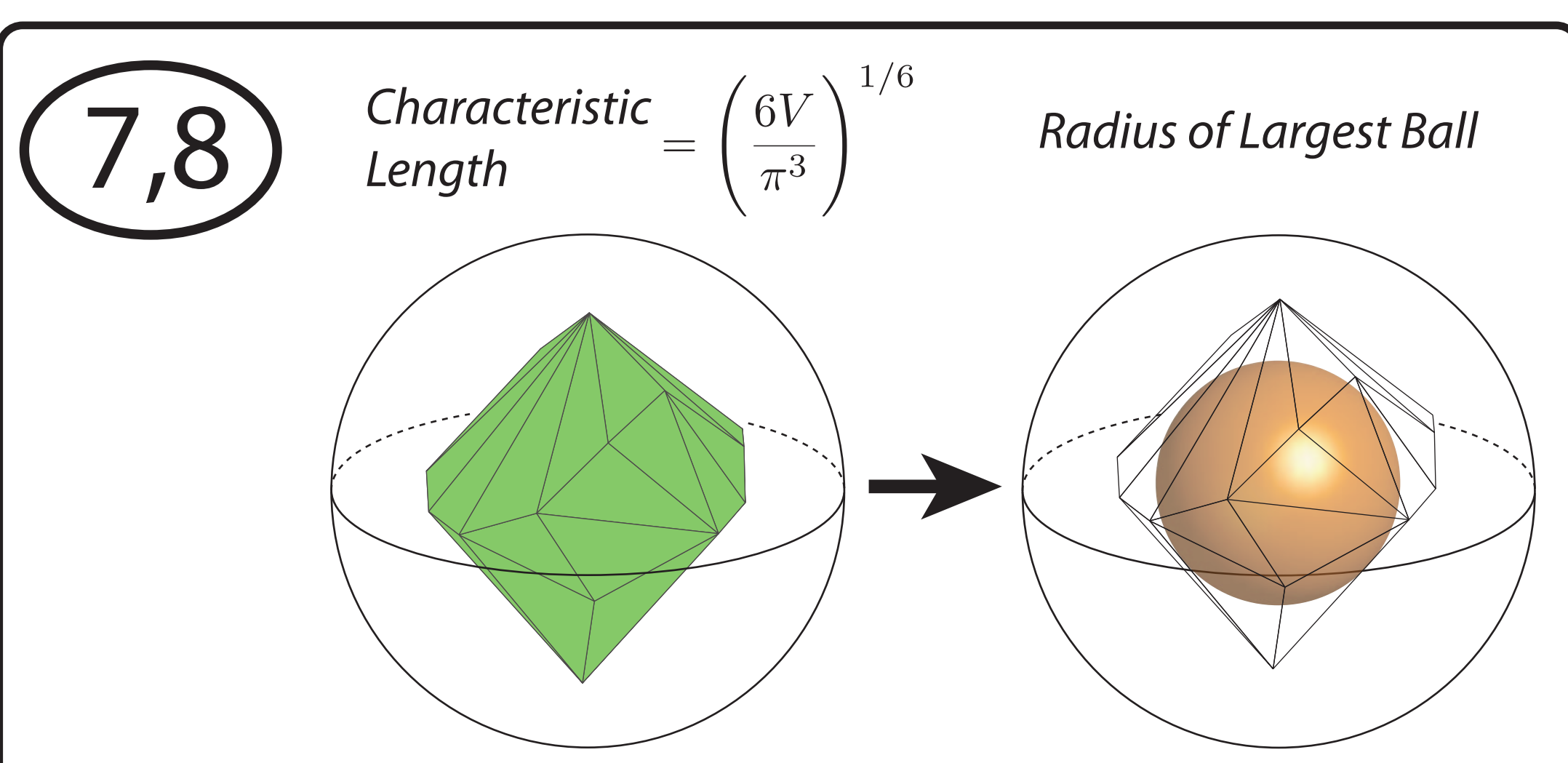

SHADOW ROBOT HAND

Methods

1. Find fingertip wrench basis vectors
2. Build fingertip feasible force set
3. Find feasible object force set
4. Simplify feasible object force set (optional)
5. Translate contact forces to object wrenches
6. Find feasible grasp wrench set
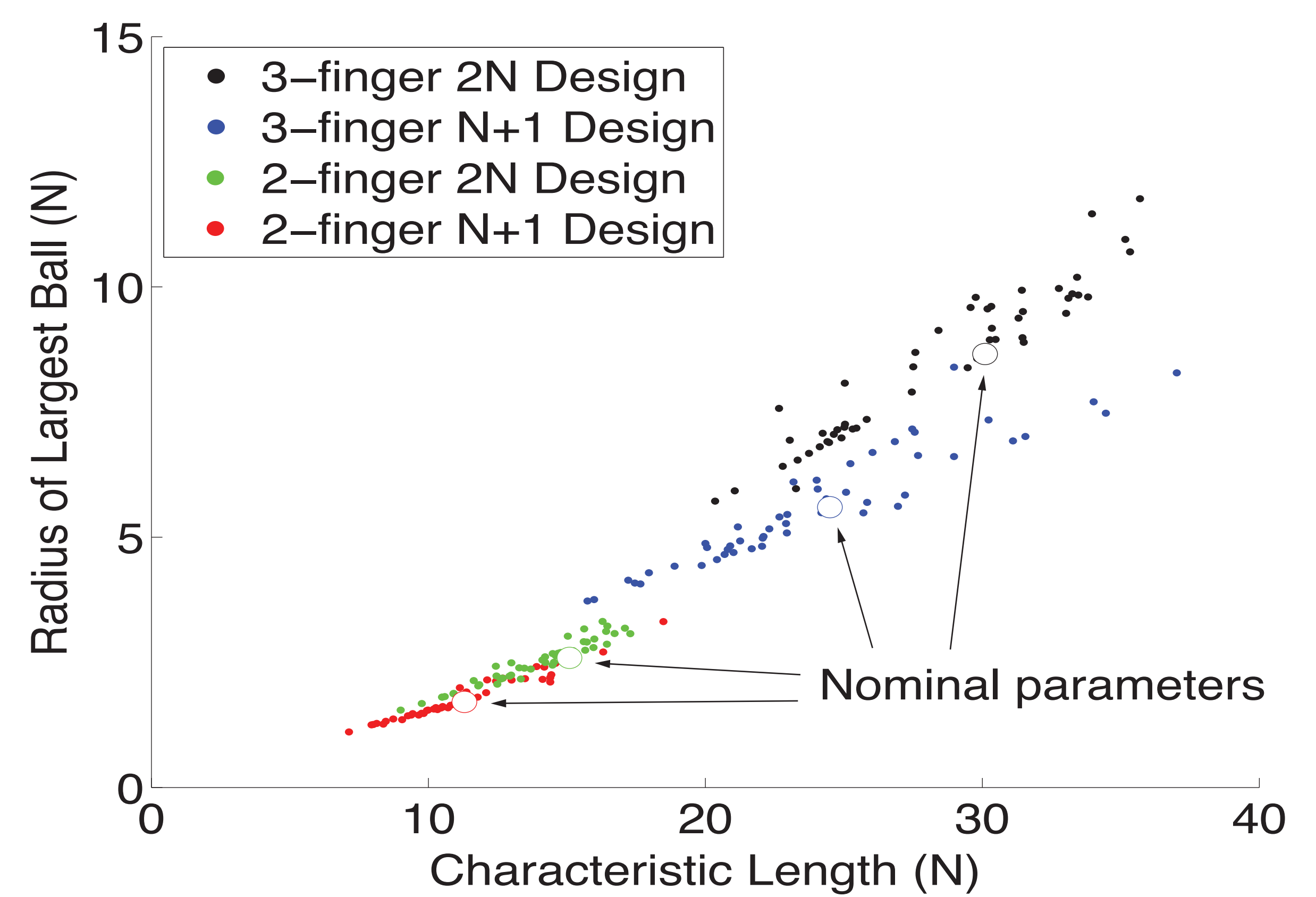7. Compute grasp quality metrics
8. Visualization (optional)

N+1 Design

2N Design

Basis vector

Feasible force set

Feasible object force set

Intersection

Friction cone

Mesh Simplification

$$\mathbf{w}_{i,j} = \begin{bmatrix} \mathbf{f}_{i,j} \\ \lambda(\mathbf{d}_i \times \mathbf{f}_{i,j}) \end{bmatrix}$$

$$FGWS = ConvexHull(\bigoplus_{i=1}^{n} \{w_{i,1}, ..., w_{i,m}\})$$

Characteristic Length $= \left(\frac{6V}{\pi^3}\right)^{1/6}$

Radius of Largest Ball

Results

Nominal and Monte Carlo results (parameters perturbed ±20%)

3–finger 2N Design
3–finger N+1 Design
2–finger 2N Design
2–finger N+1 Design

Radius of Largest Ball (N)

Characteristic Length (N)

Nominal parameters

Characteristic Length for 2-finger grasp

2N Design

Iteration Count

Top 5% of 2N topologies

N+1 Design

Iteration Count

4 N+1 topologies contained in this range

Characteristic Length (N)
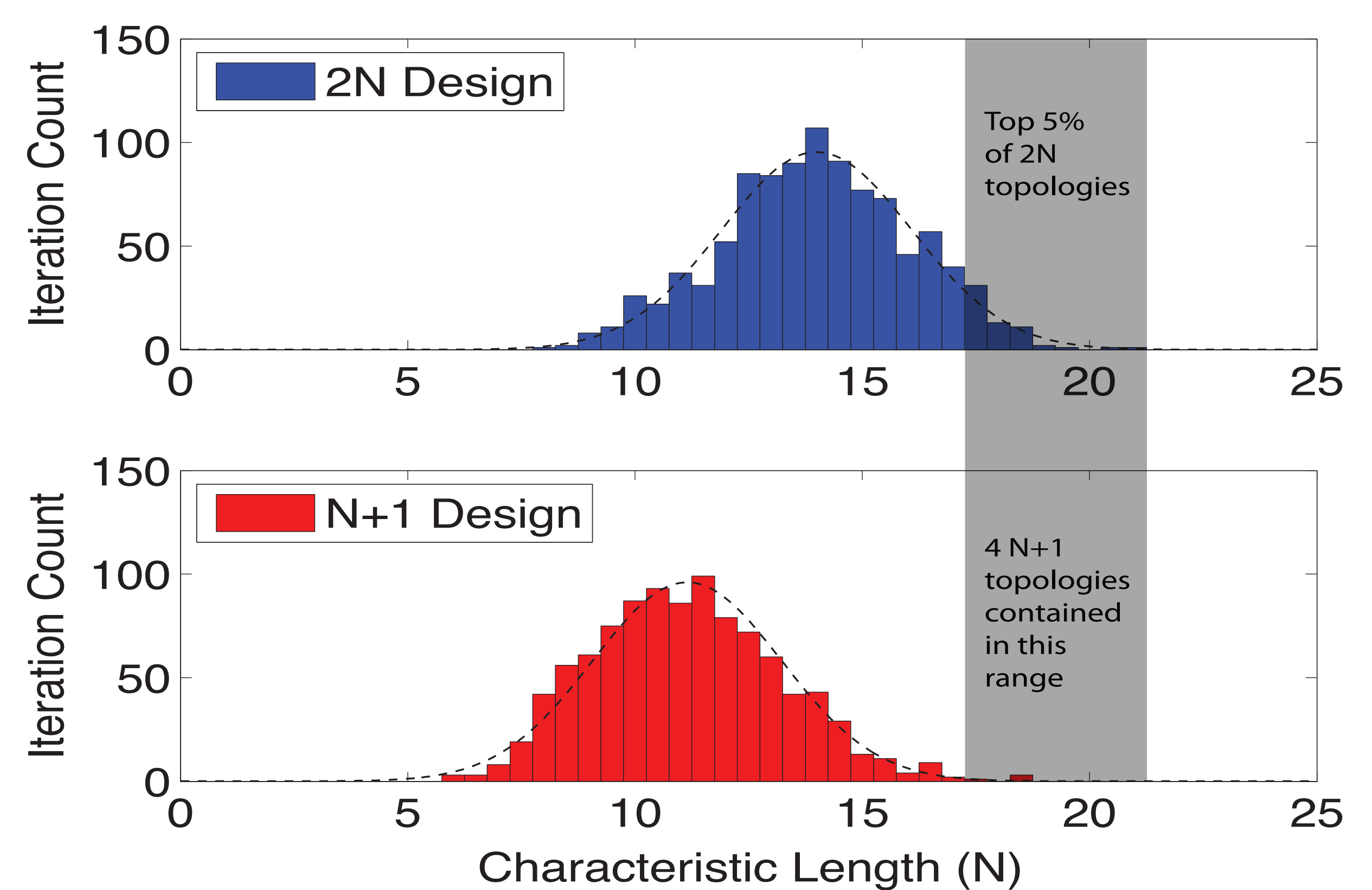
Conclusions and future work

• We successfully developed and implemented this methodology for use in analyzing the grasp capabilities of tendon-driven hands.

• Monte Carlo results show that:
  – topology greatly affects grasp quality.
  – grasp quality can be vastly affected by making modest changes in parameters.
  – simpler topologies can be designed to outperform more complex ones.

• *Future work will use this methodology to design dexterous, tendon-driven hands with higher grasp capabilities than are currently available, and simpler hands with specific capabilities.*

• In addition, this work also enables mechanical design aimed at both producing function and enabling specific control strategies for motion and force control.

References
1. Pons JL et al. Robotica 54, 674, 1999. 2. Tsai LW. J of Mech Design 117, 80, 1995.