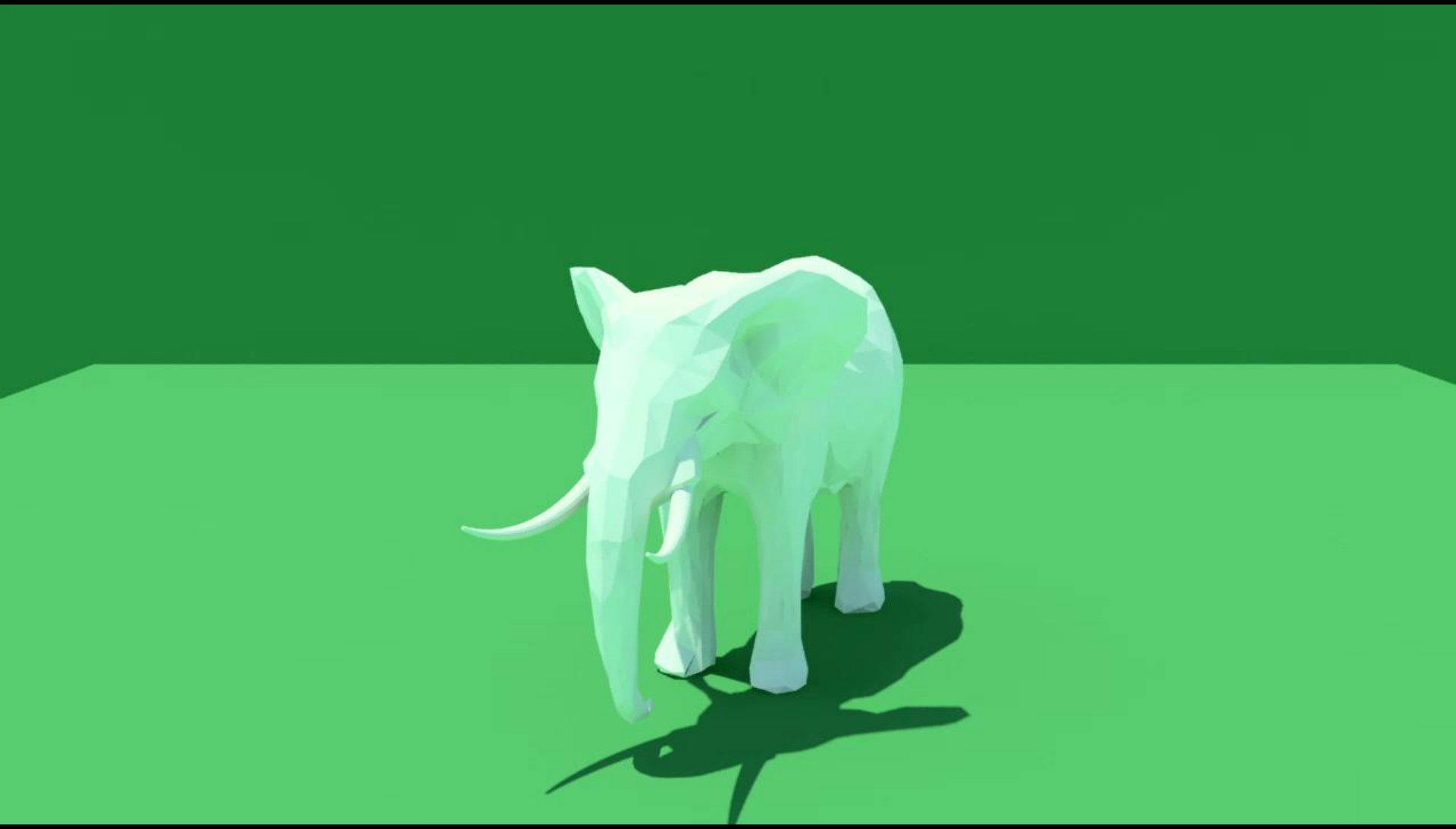
SIGGRAPH ASIA 2012

UCL

3D Printing of Non-Assembly Articulated Models

Jacques Calì, Dan Andrei Calian, Cristina Amati, Rebecca Kleinberger, Anthony Steed, Jan Kautz, Tim Weyrich

Problem Statement



Challenges with Printing Articulated Models

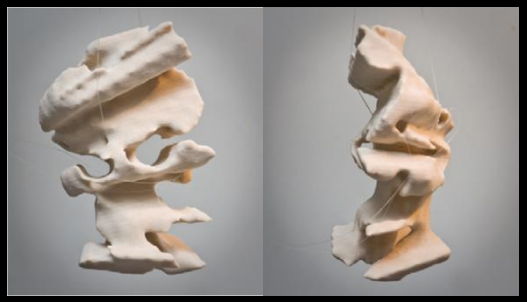
- Design issues
  - Labour intensive
  - Requires skilled modeller
- 3D printing issues
  - Limited resolution
  - Support material / structure
  - Fusing of interlocking parts

Related Work

- Sculptures

  [Xin et al. 2011]

  [Mitra and Pauly 2009]



- Deformable objects

  [Bickel et al. 2010]

- Joints that form robots

  [Won et al. 2000]

  [Mavroidis et al. 2001]

Concurrent Work [Bächer et al. 2012]

- Joints properties
  - Friction
  - Rotational constraints set from default parameters

  - Locations extracted from skinning
  - User can select between 1 or 3 DOF

Contributions

- Derived a directly printable versatile joint template:
  - friction
  - non-assembly
  - controllable rotational constraints

- Interactive joint fitting pipeline
- A set of underlying algorithms to support it

Deriving a Generic Joint Template

Generic Joint Template

- Design criteria
  - Wide range of angular positions
  - No locking configurations
  - Intuitive rotational constraints control
  - Support for friction
  - Non-assembly printing
  - Compact appearance

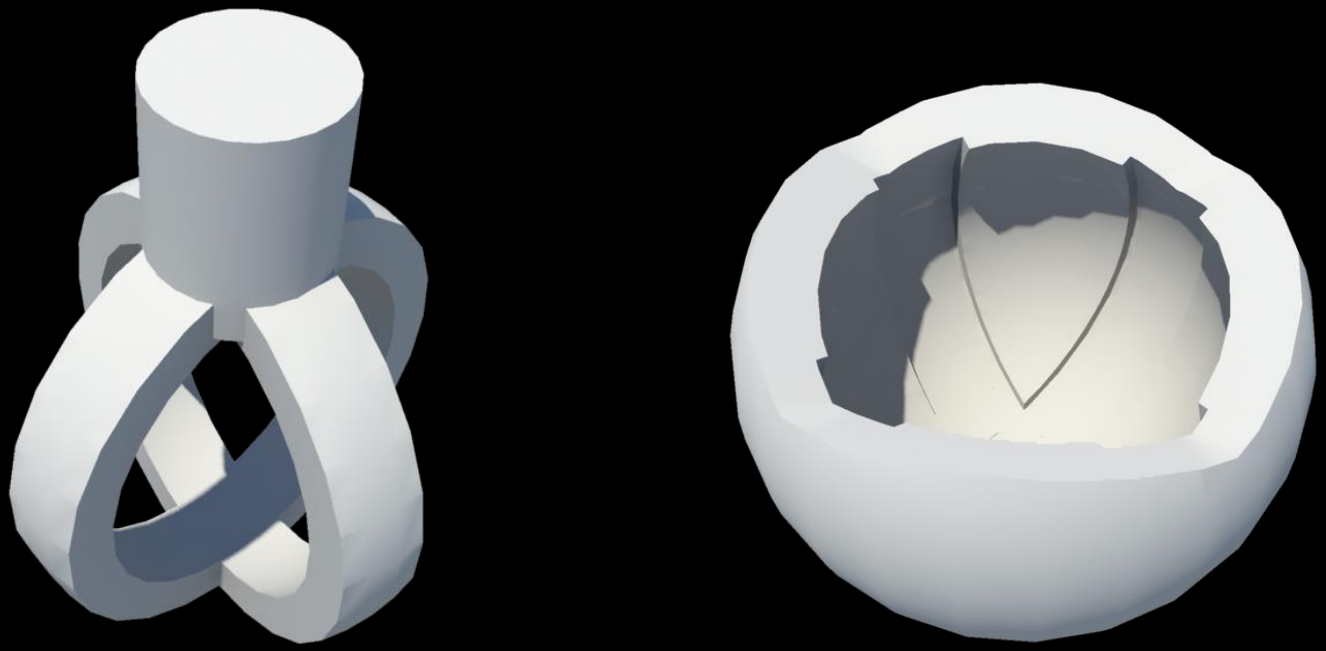
Joint Exploration

Ball Joint

- Solution builds upon the ball-and-socket joint, as it:
  - Spans a wide range of angles
  - No locking
  - Customizable rotational constraints

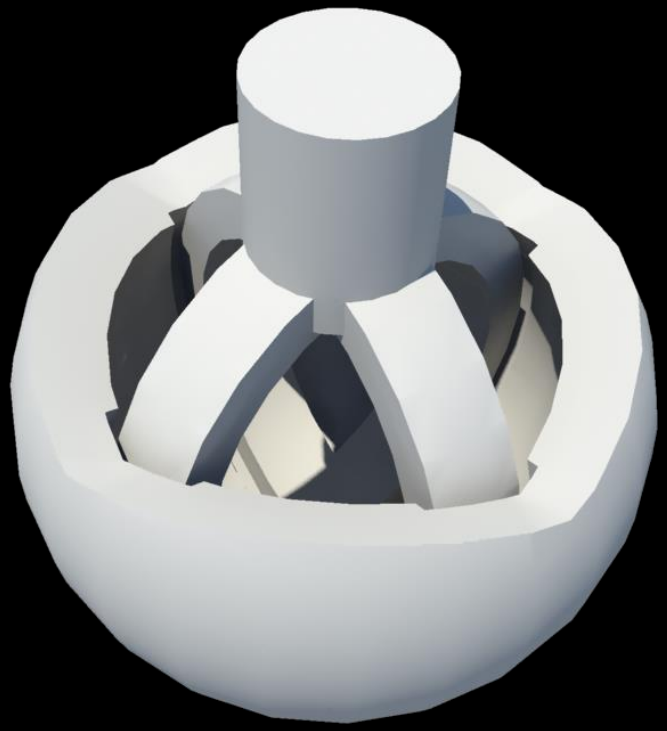
Solution

- Cage ball and grooved socket



Solution

- Cage ball and grooved socket

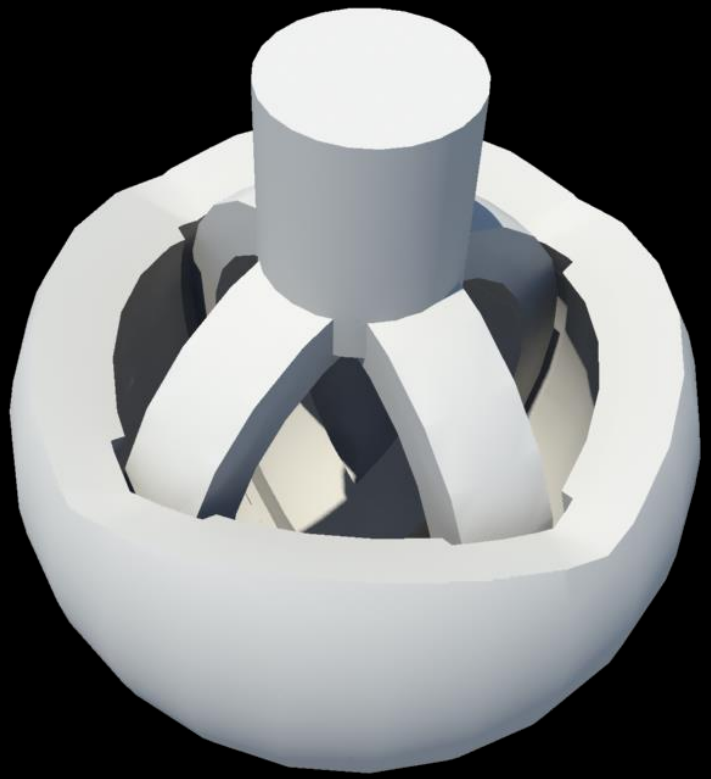


Printability

- Support material in Selective Laser Sintering / Polyjet
  - Fills in gaps
  - Blocks moving parts

Printability

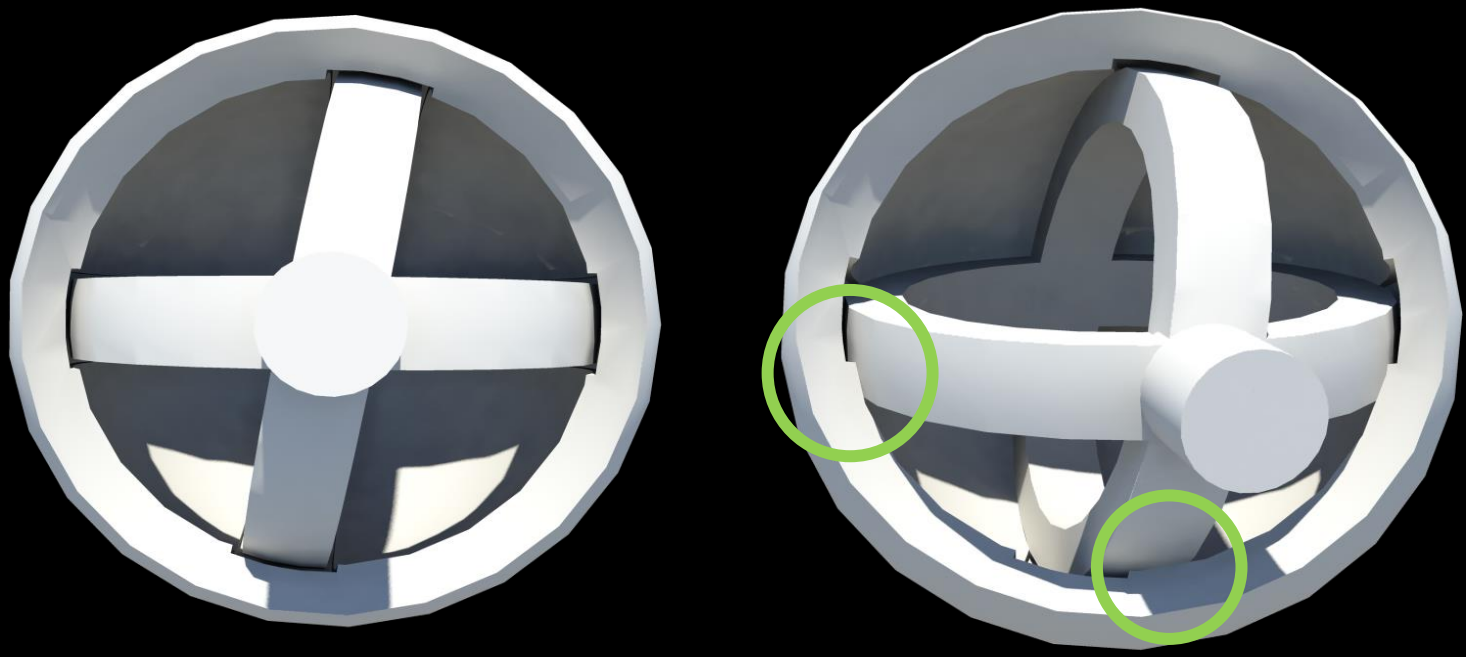
- Support material in Selective Laser Sintering / Polyjet
  - Fills in gaps
  - Blocks moving parts
  - External access to it is required
  - Our joint template facilitates access



Rotational Constraints Control

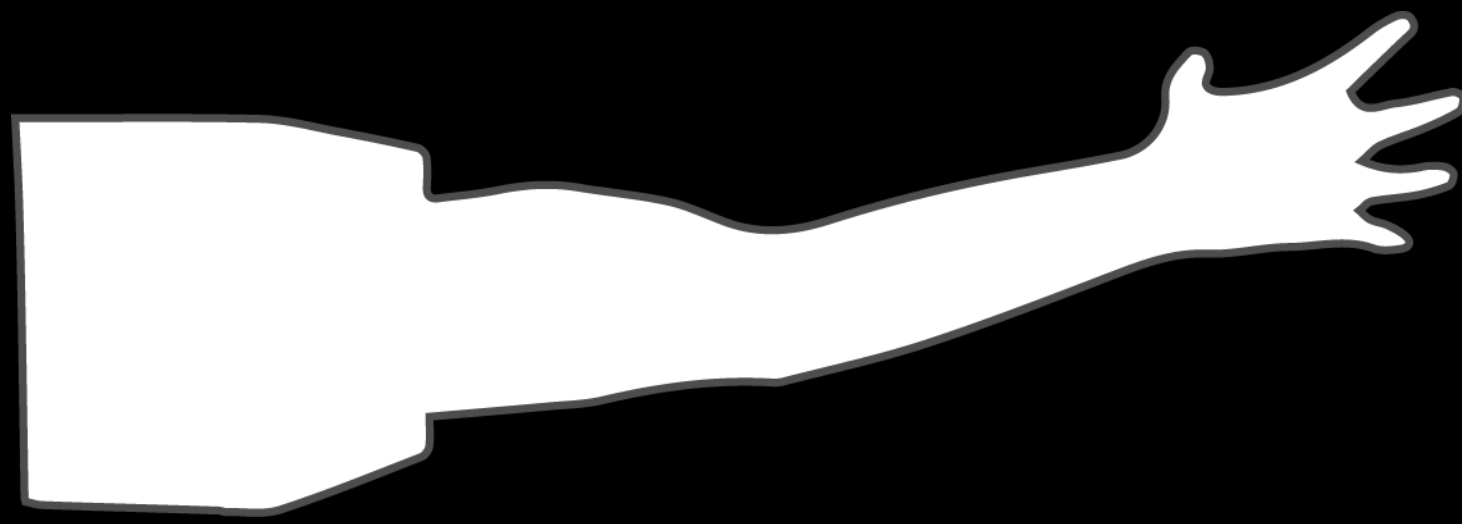
- Socket opening is shaped according to user-specified constraints

Friction

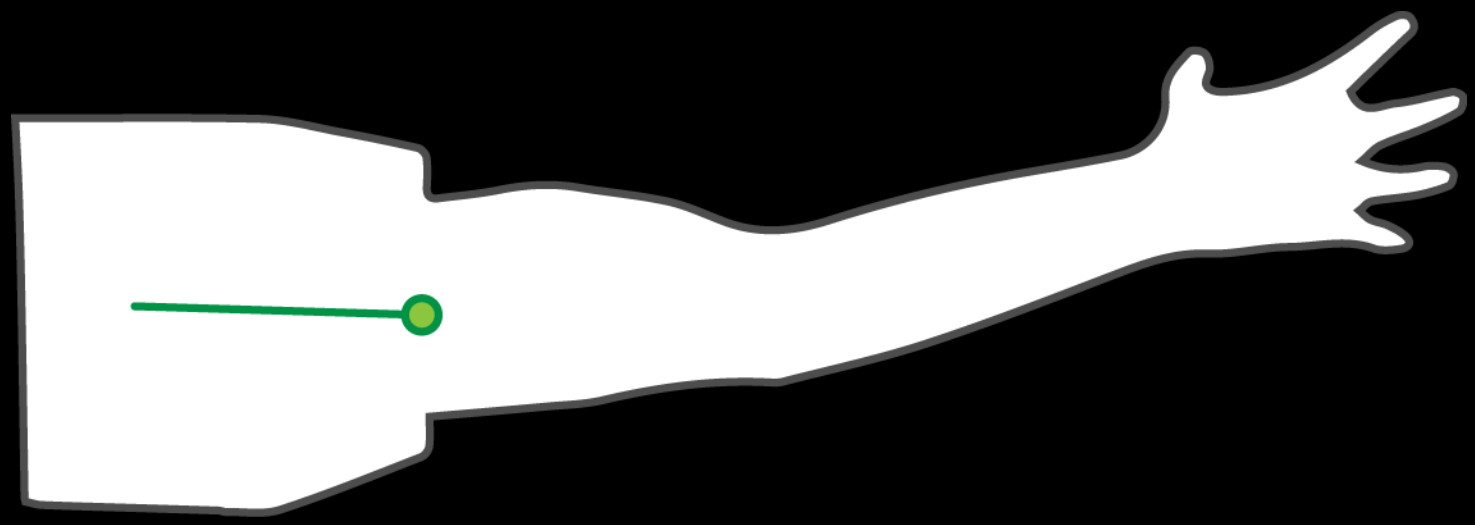


Workflow

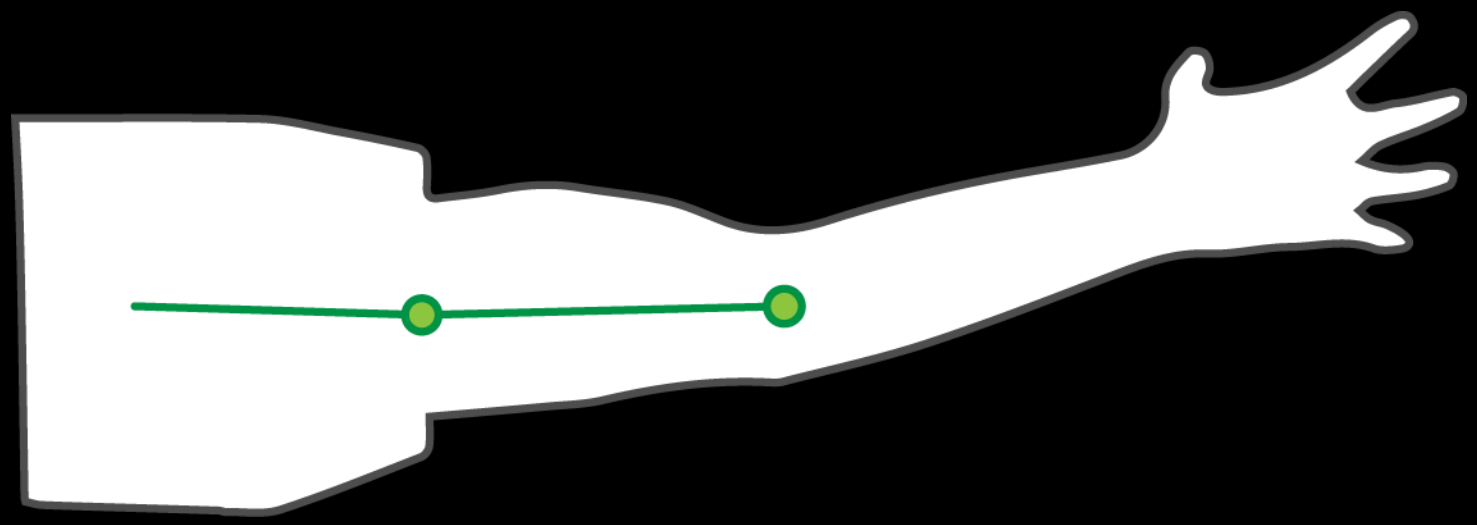
Rigging for 3D Printing



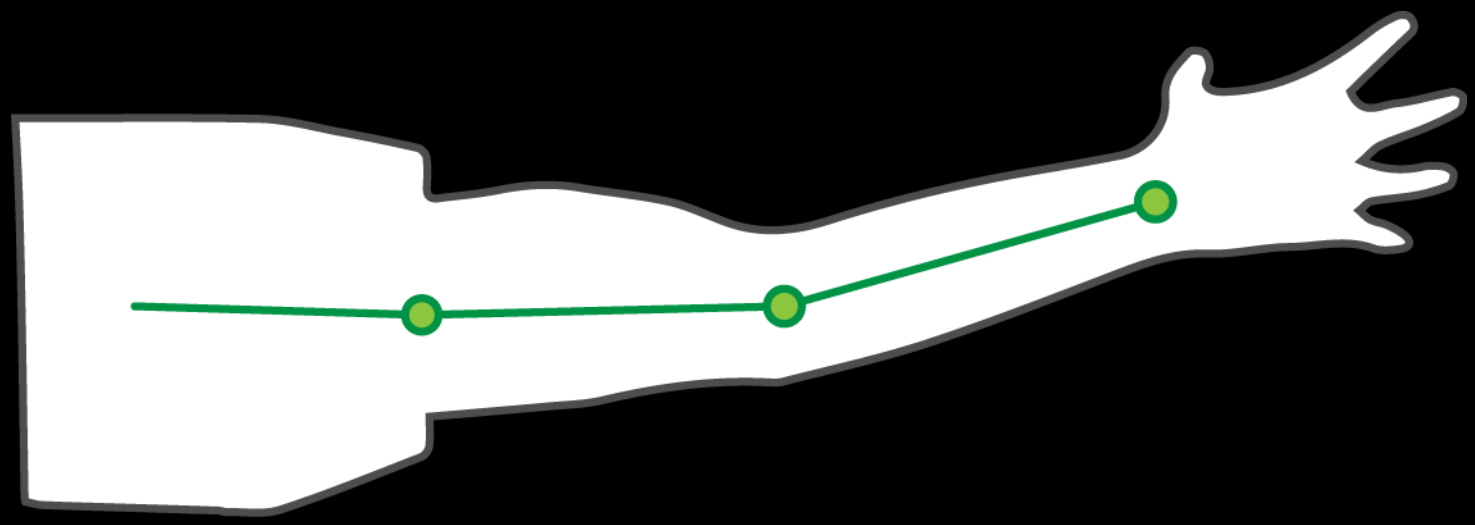
Rigging for 3D Printing



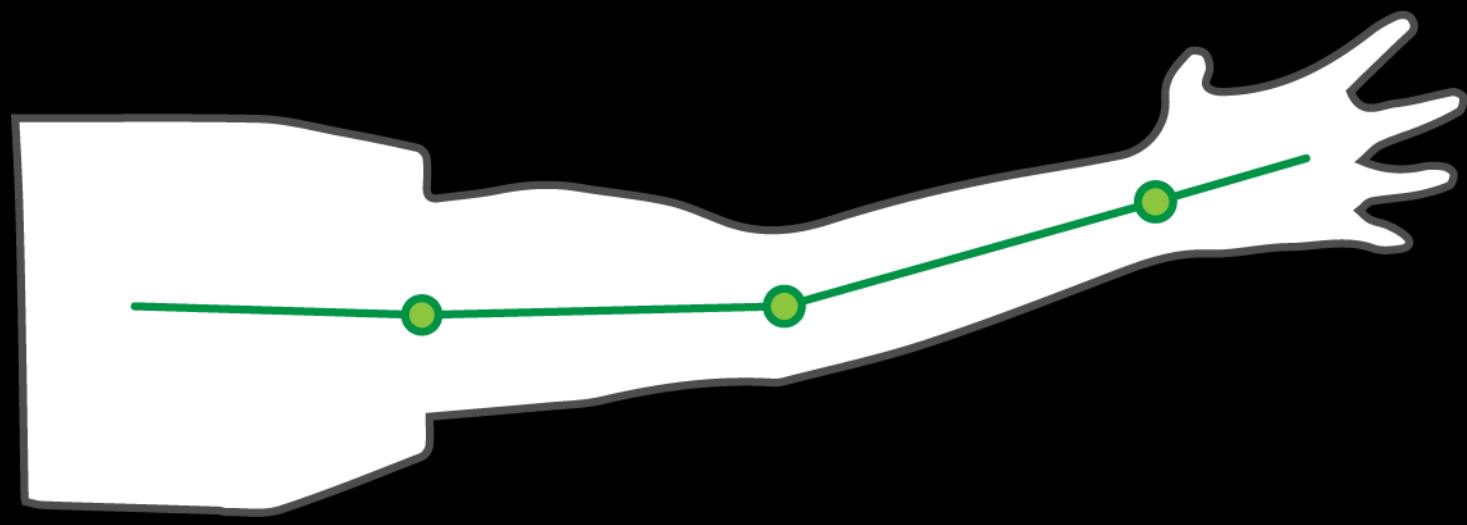
Rigging for 3D Printing



Rigging for 3D Printing

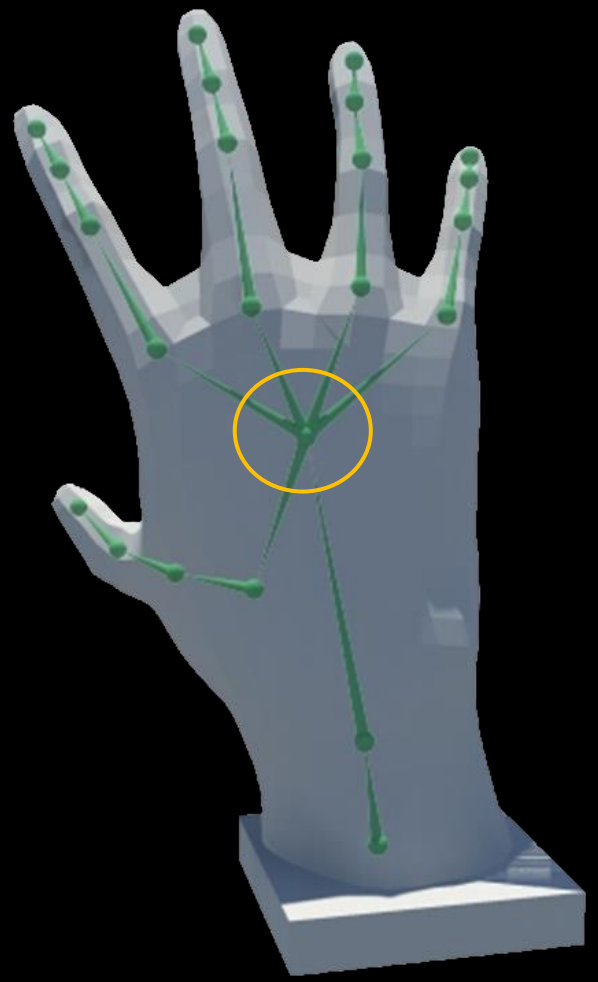


Rigging for 3D Printing

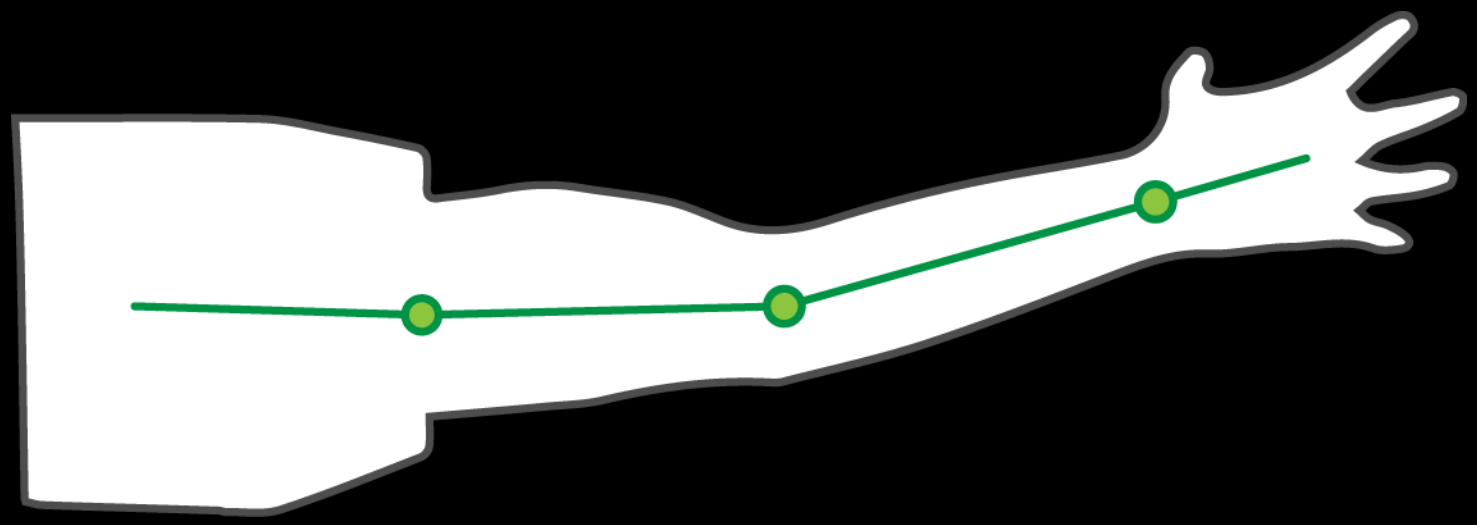


Rigging for 3D Printing

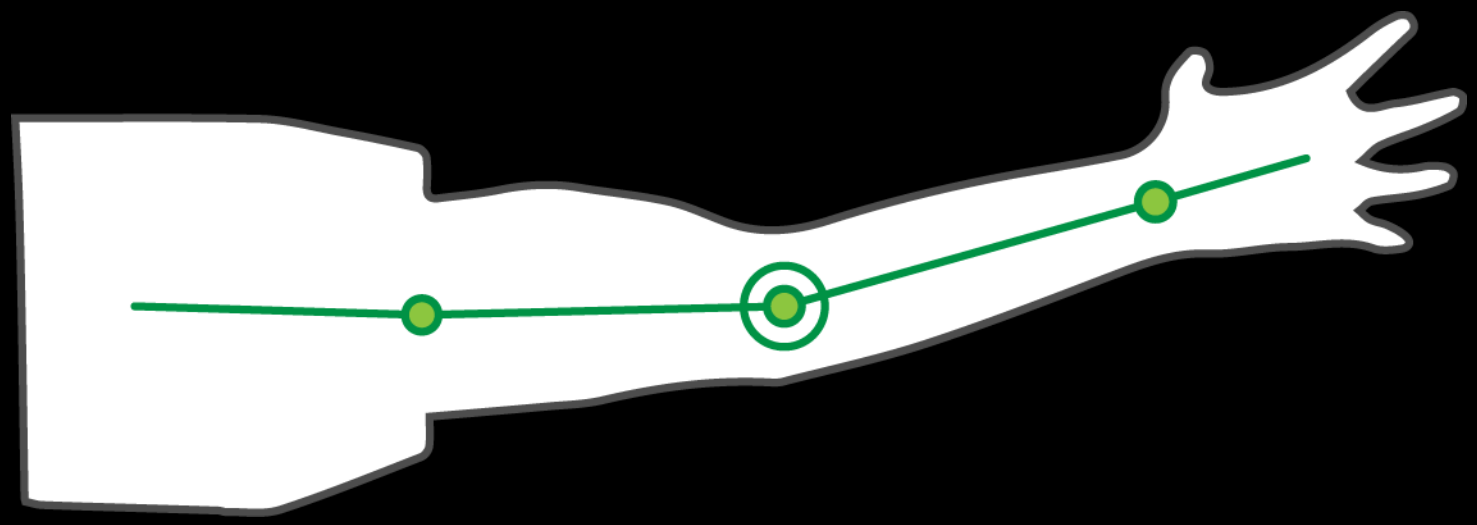
- Intuitive rigging:
  - Place connectors at joint locations
  - Connectors with >2 connectivity are not joint locations



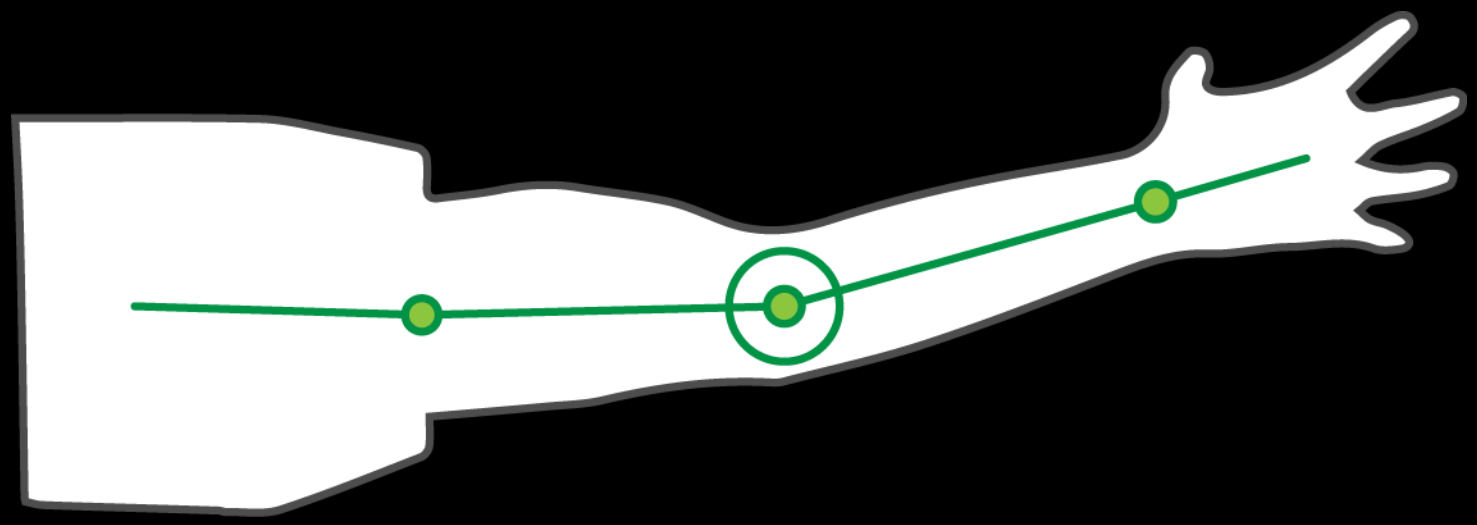
Joint Scale



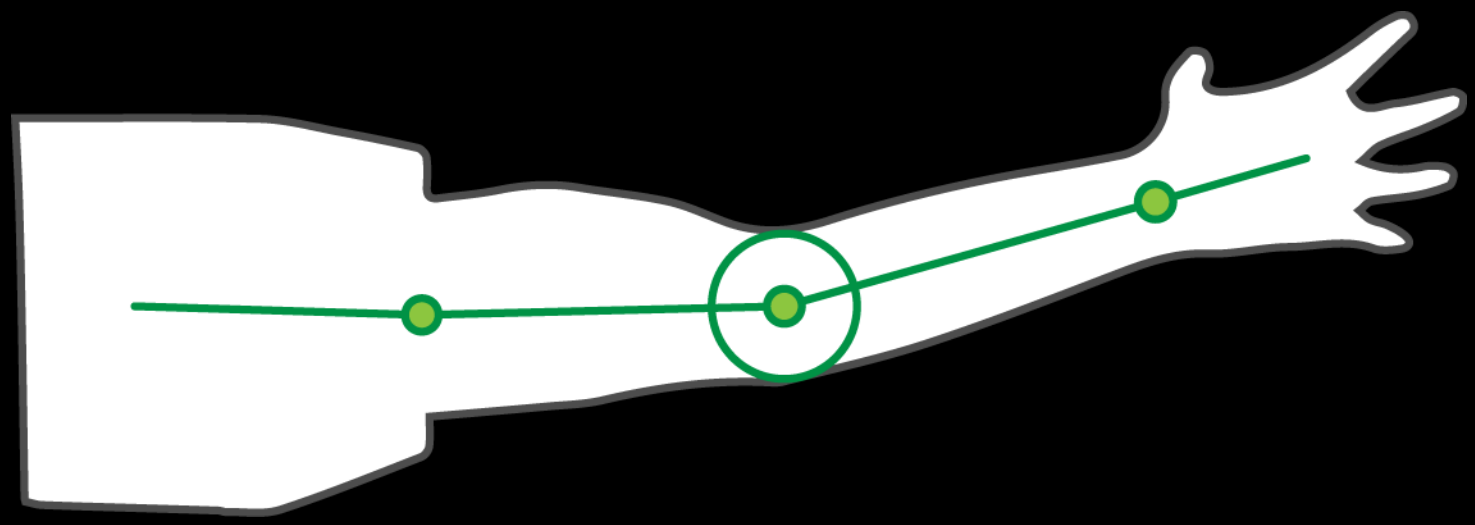
Joint Scale



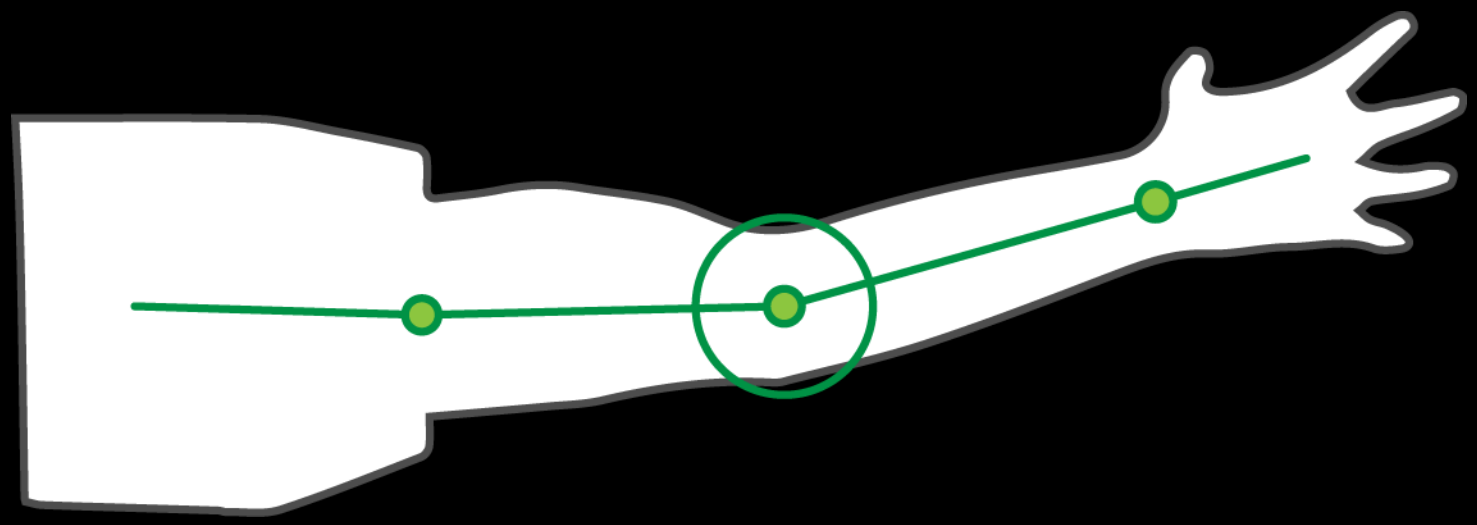
Joint Scale



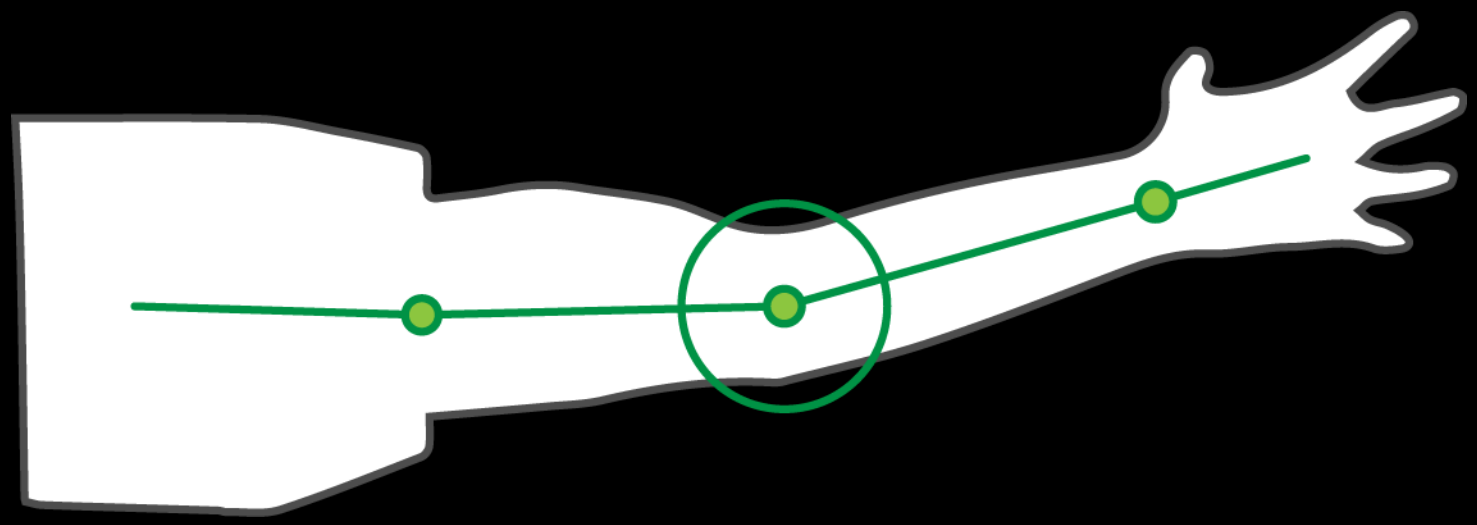
Joint Scale



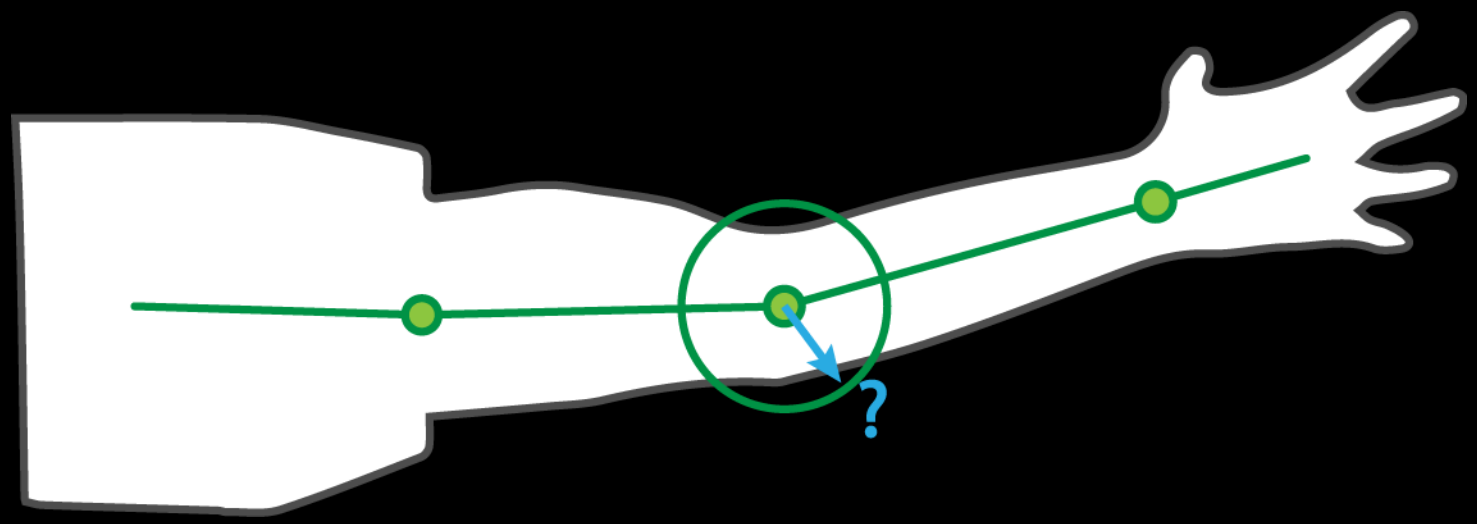
Joint Scale



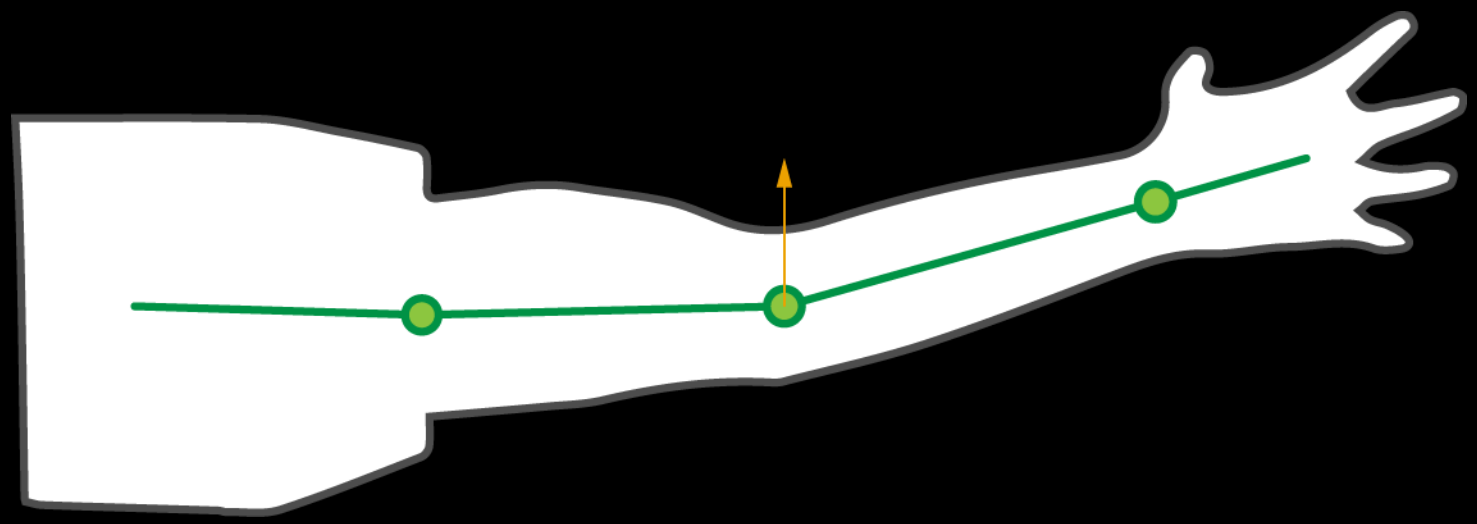
Joint Scale



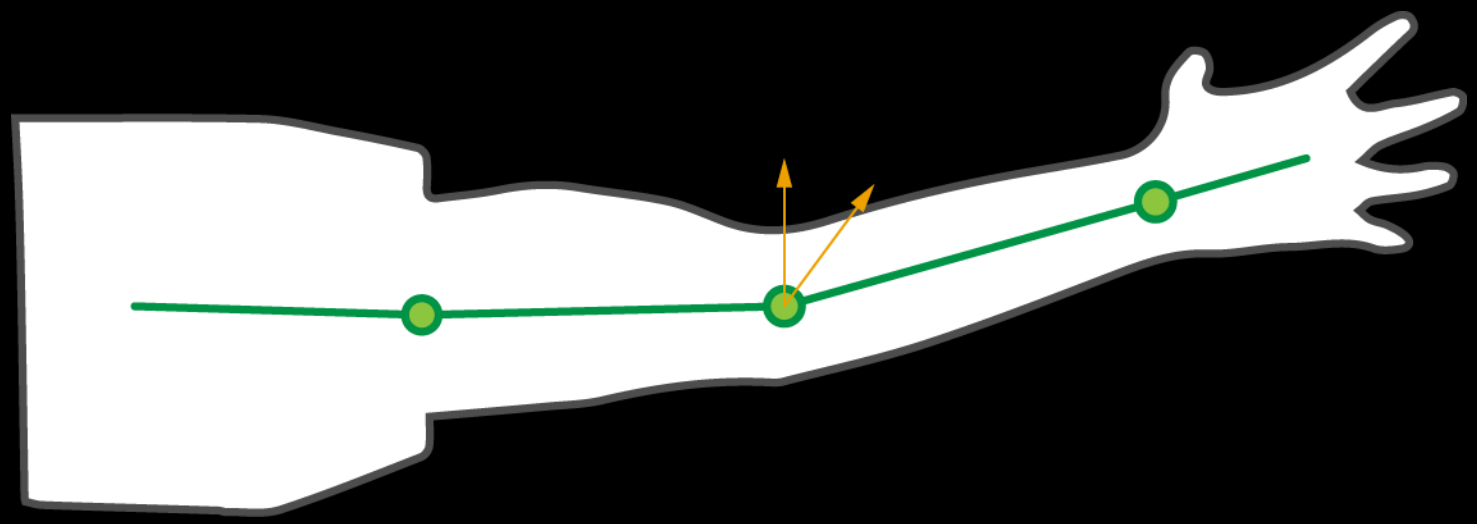
Joint Scale



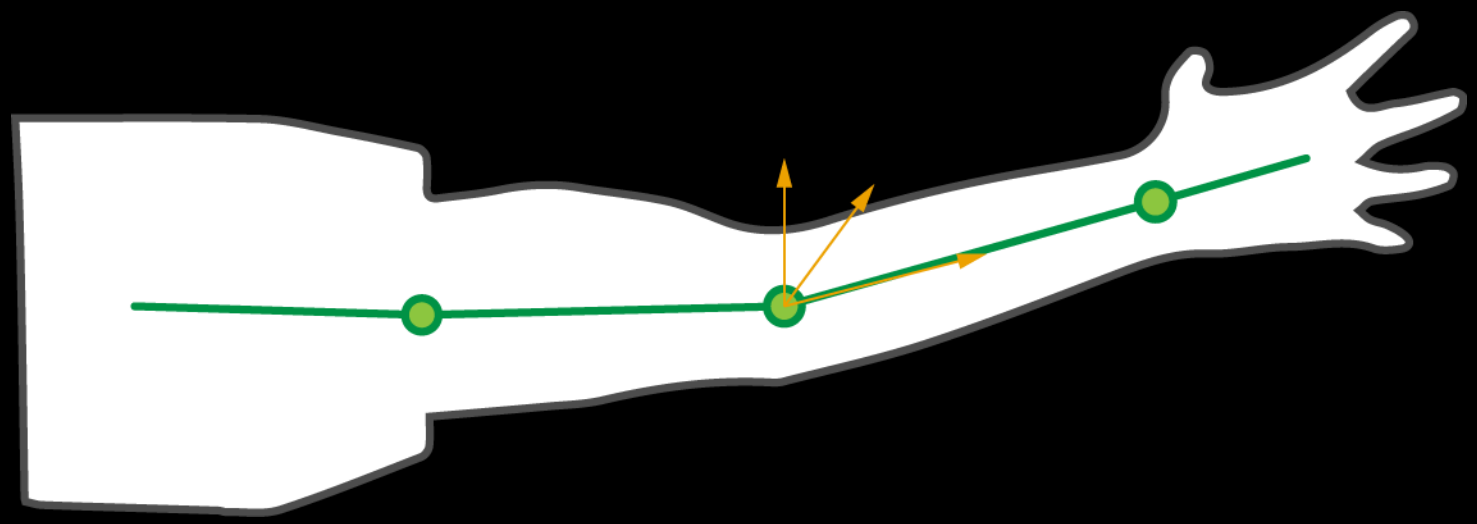
Joint Scale



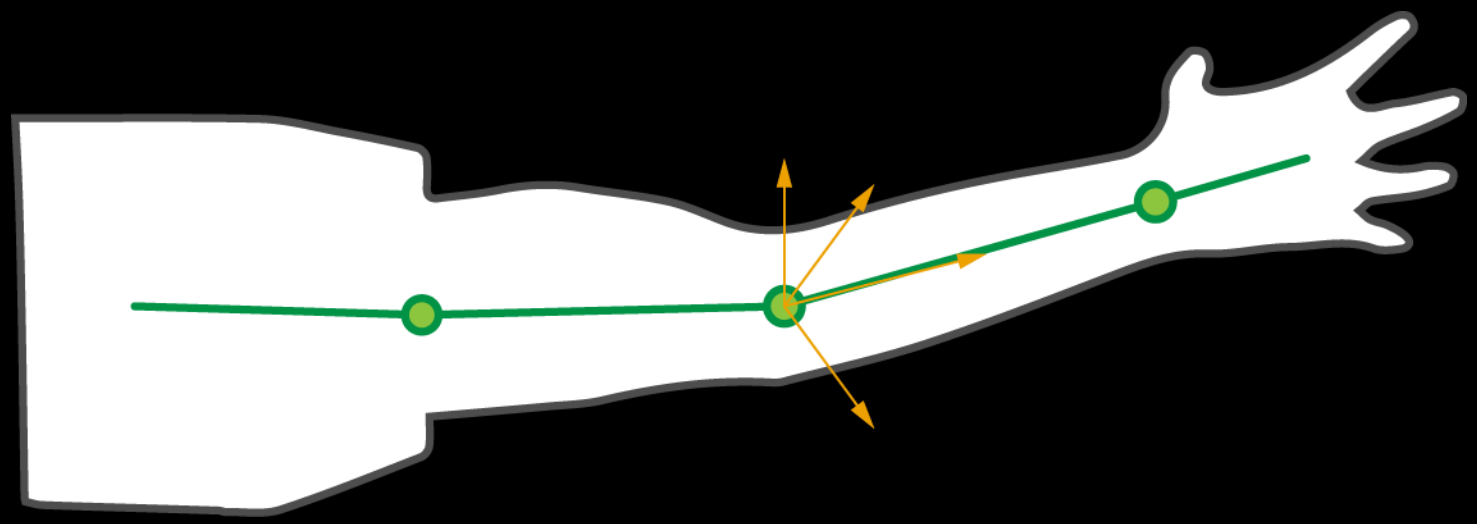
Joint Scale



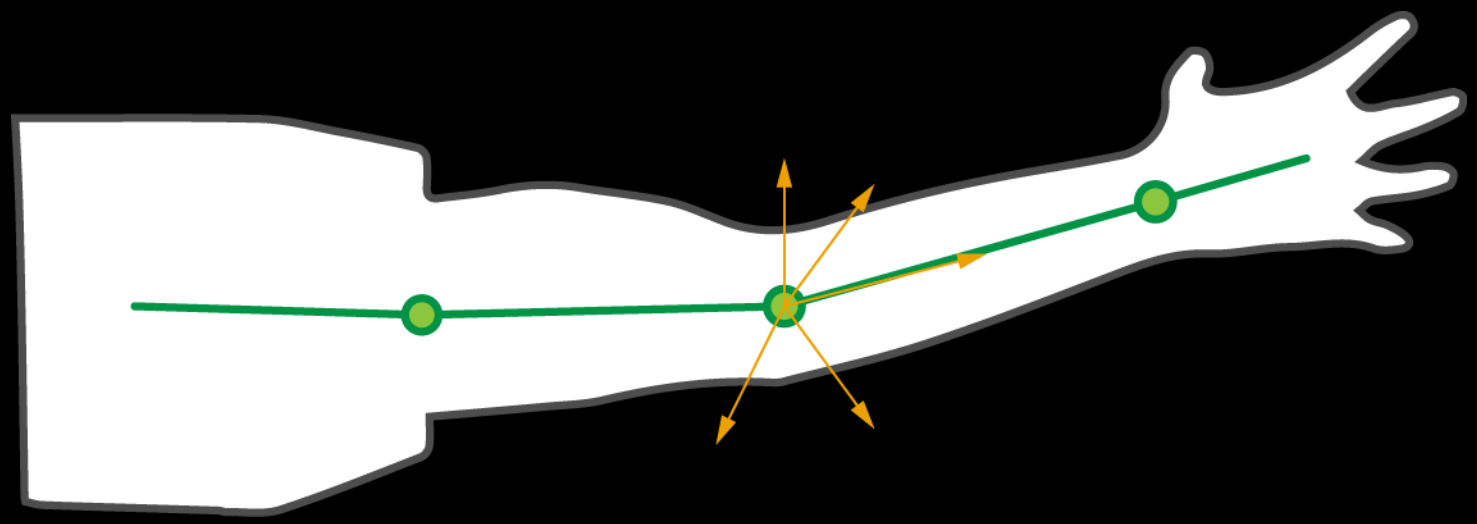
Joint Scale



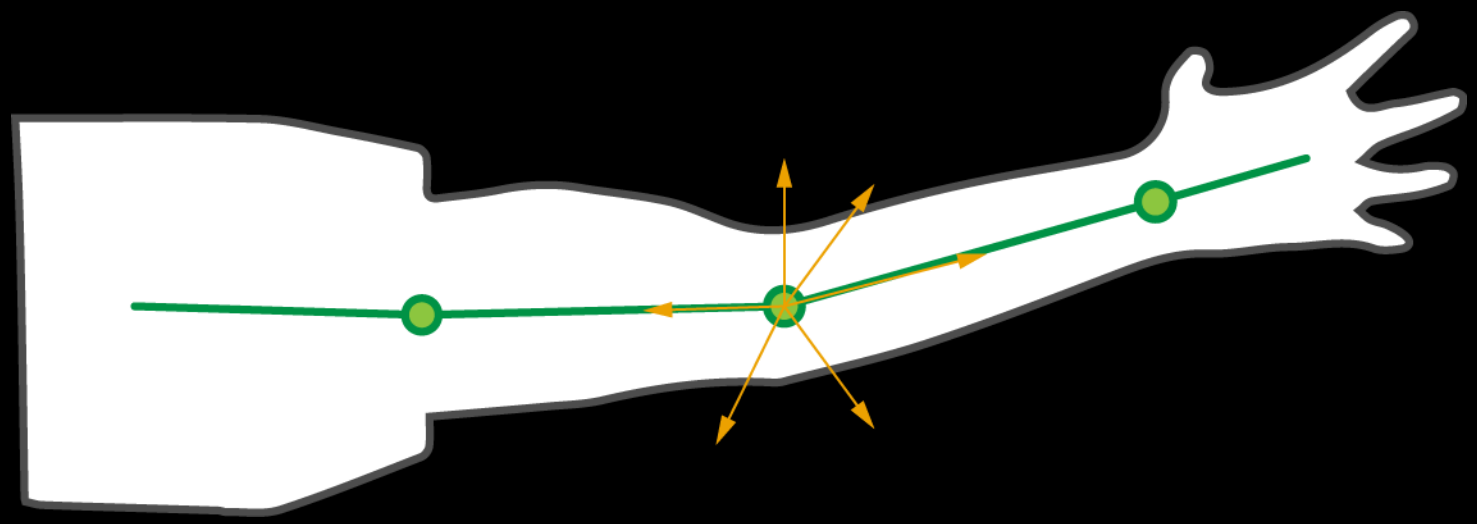
Joint Scale



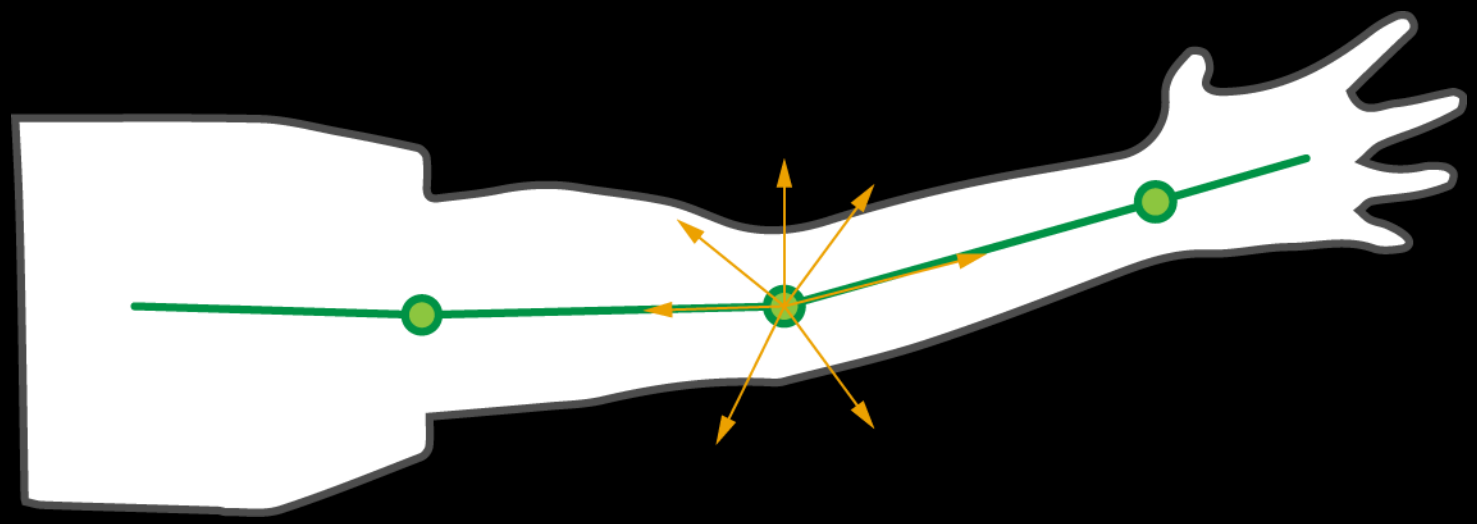
Joint Scale



Joint Scale



Joint Scale

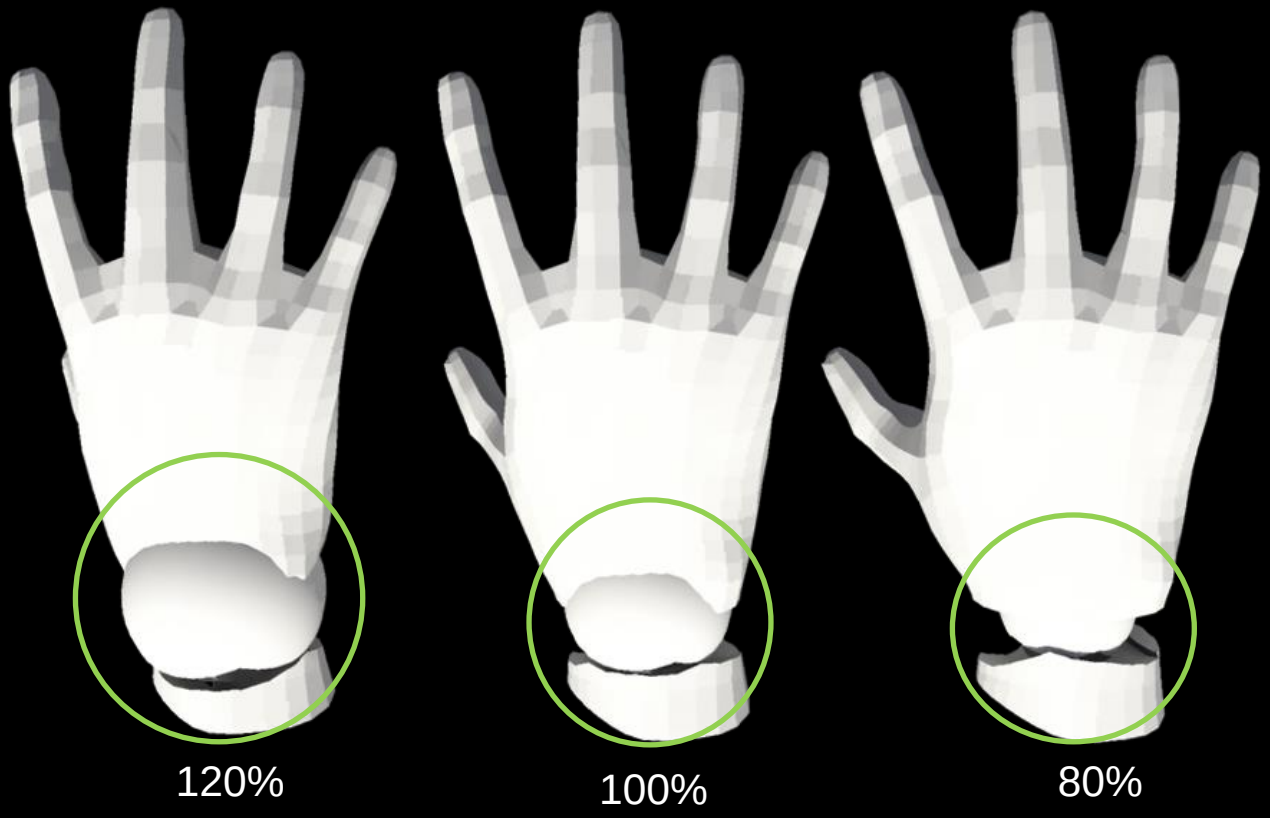


Joint Scale

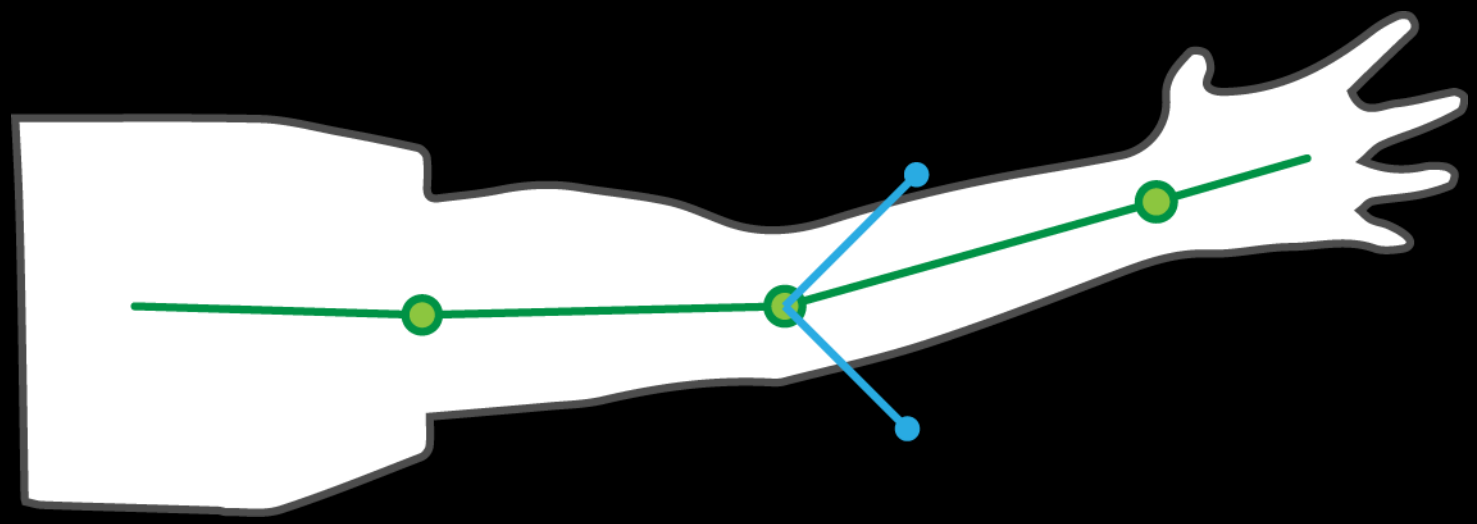
- Cast rays from joint centre outwards, filtering-out rays within 45 degrees of the bones
- Fitting sphere using RANSAC to resulting point cloud

Joint Scale - Aesthetics

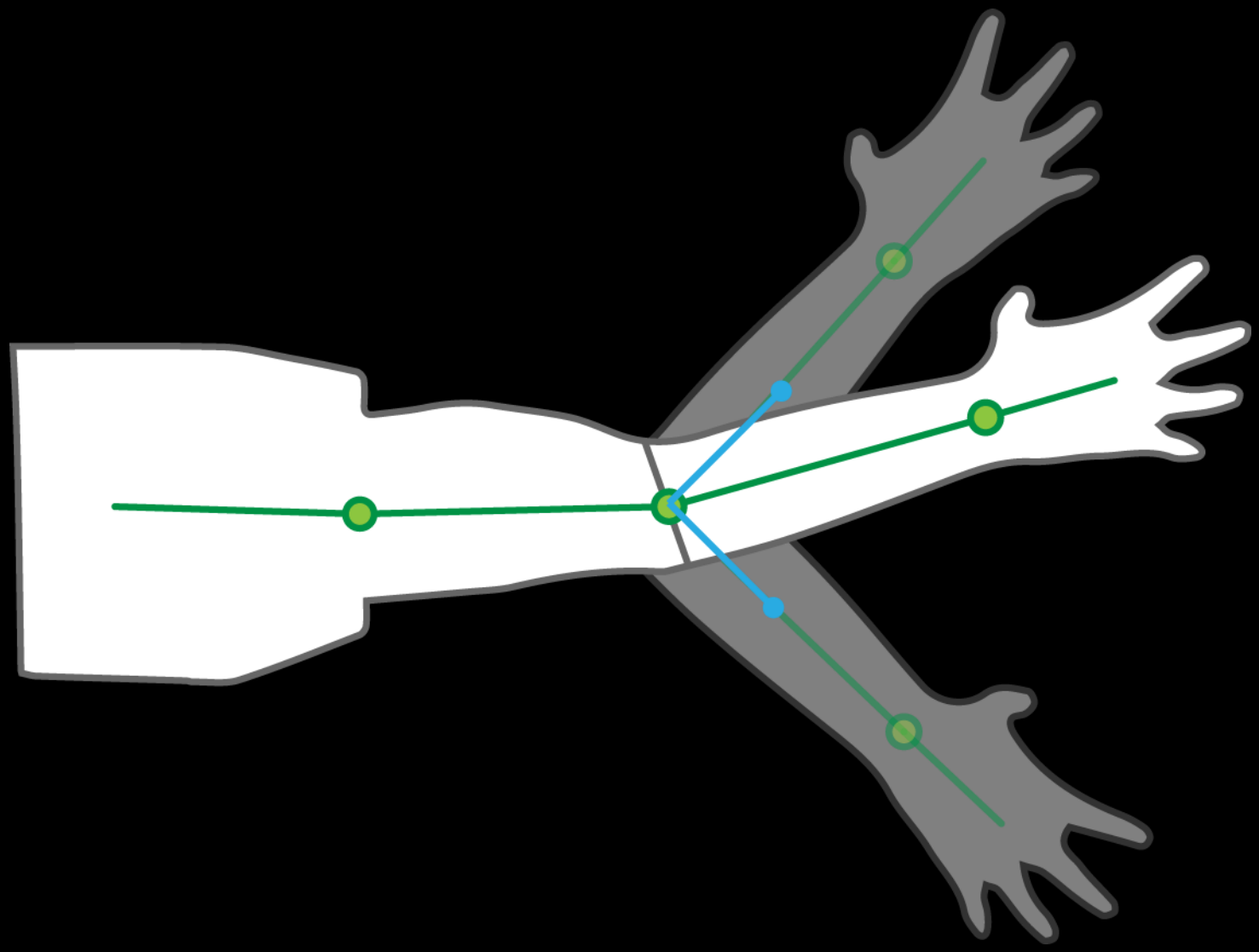
- Manual scaling of computed sizes allows for control over aesthetic preferences



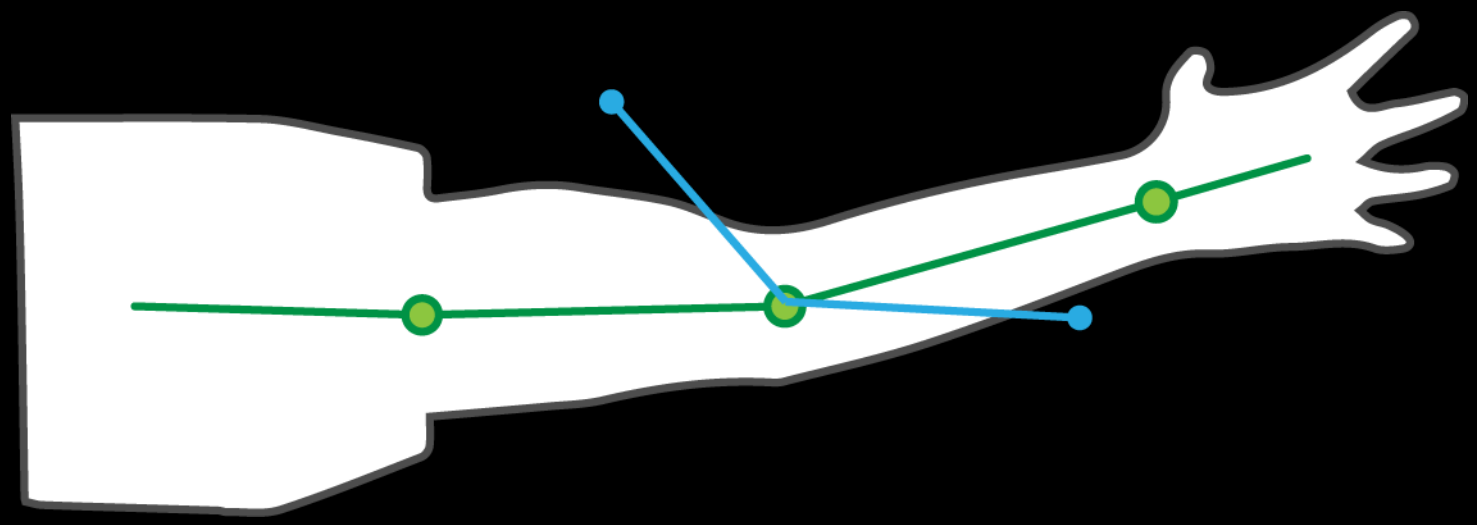
Shaping Rotational Constraints



Shaping Rotational Constraints

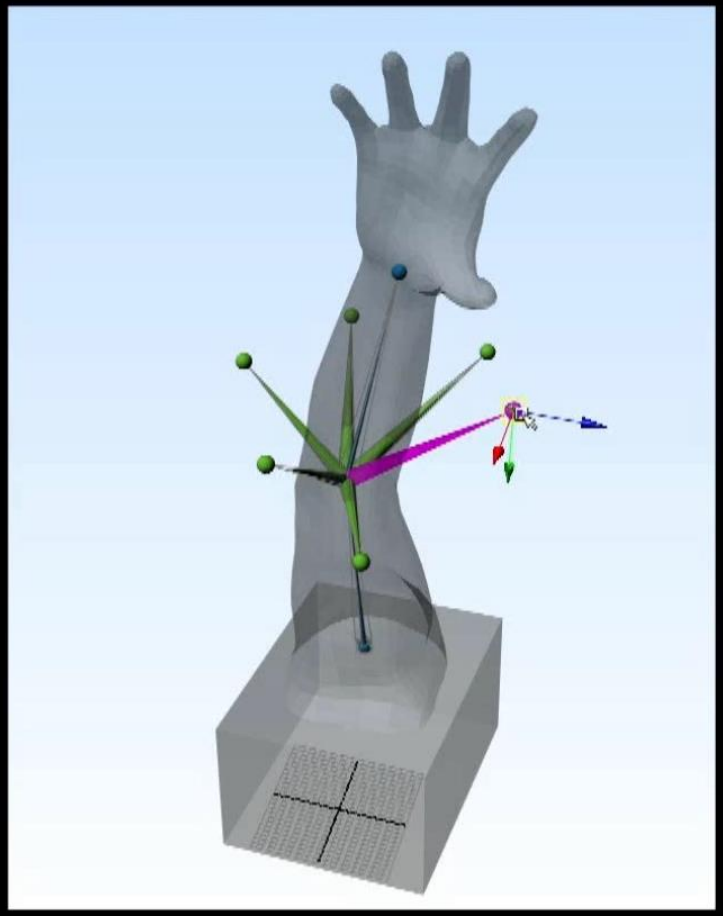


Shaping Rotational Constraints

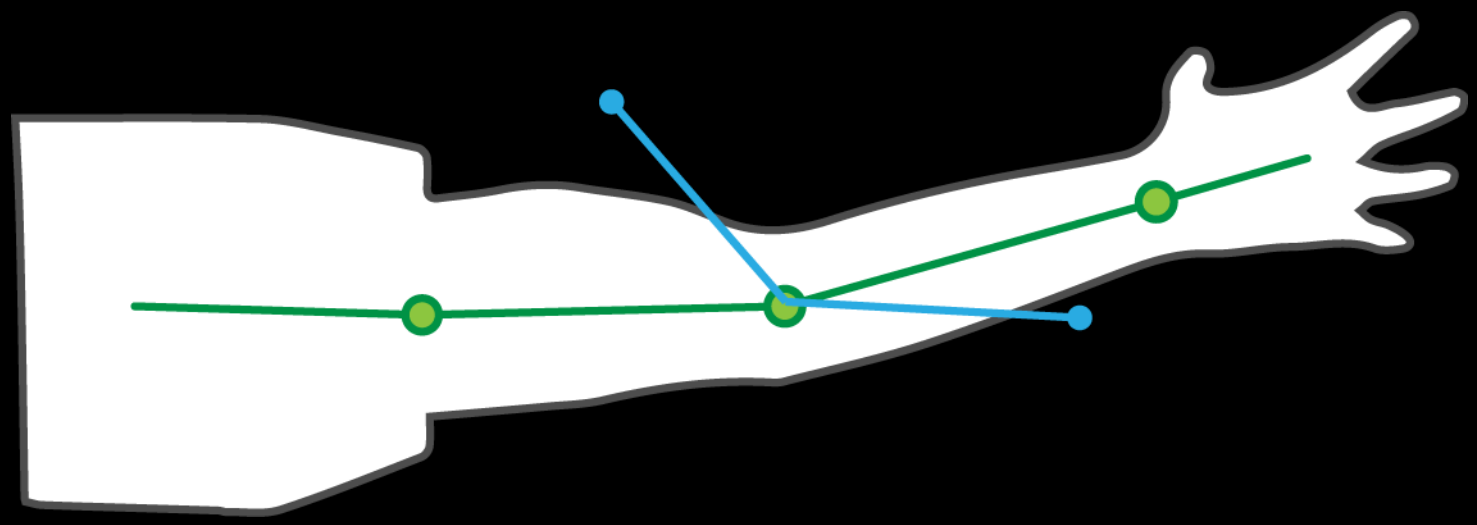


Shaping Rotational Constraints

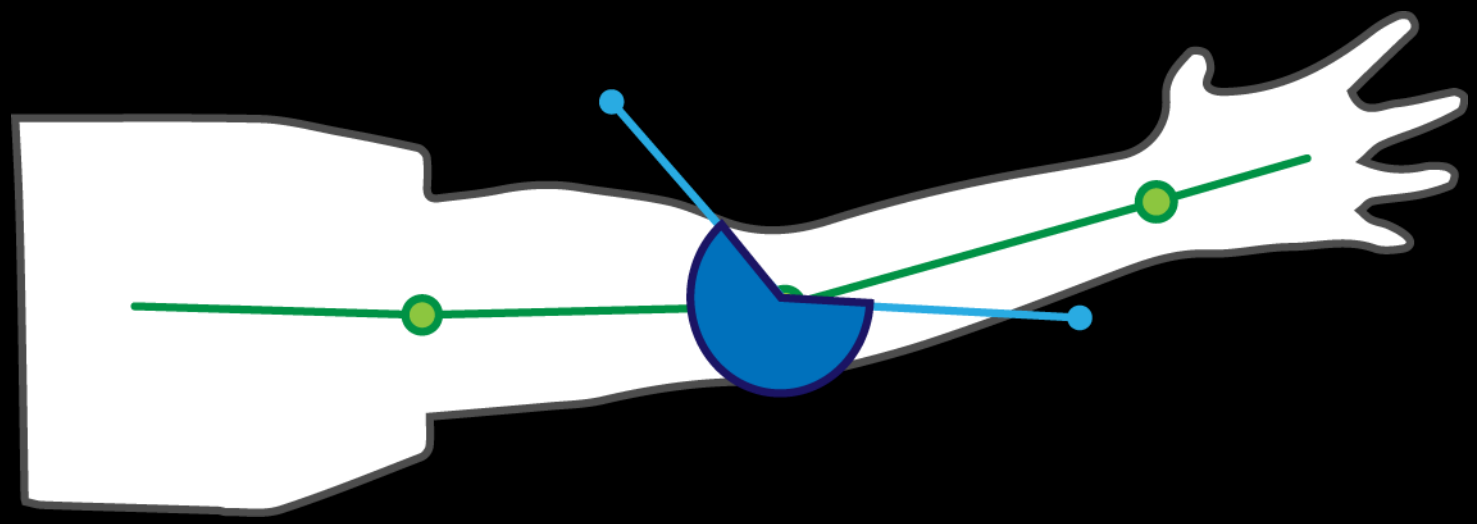
- Users design joints' rotational constraints by dragging pins
- The pins specify rotational extremes



Joint Shaping



Joint Shaping



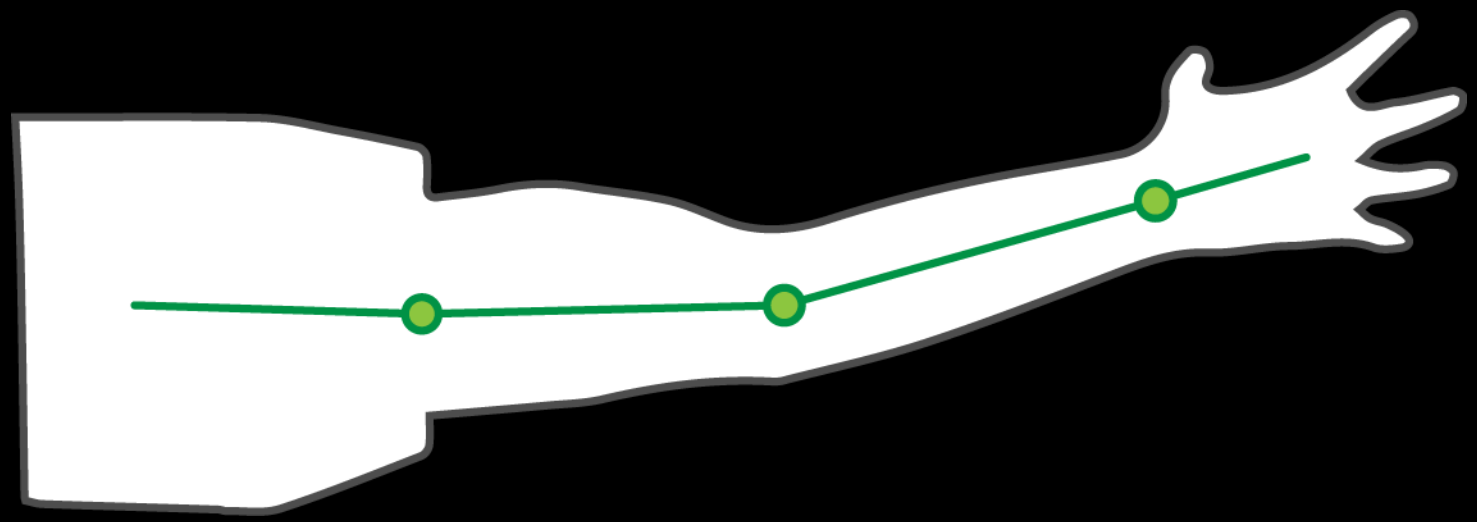
Joint Shaping

- Take the generalised cone defined by the rotational constraint pins
- Subtract it from socket using CSG
- We dilate the cone to compensate for the shaft thickness

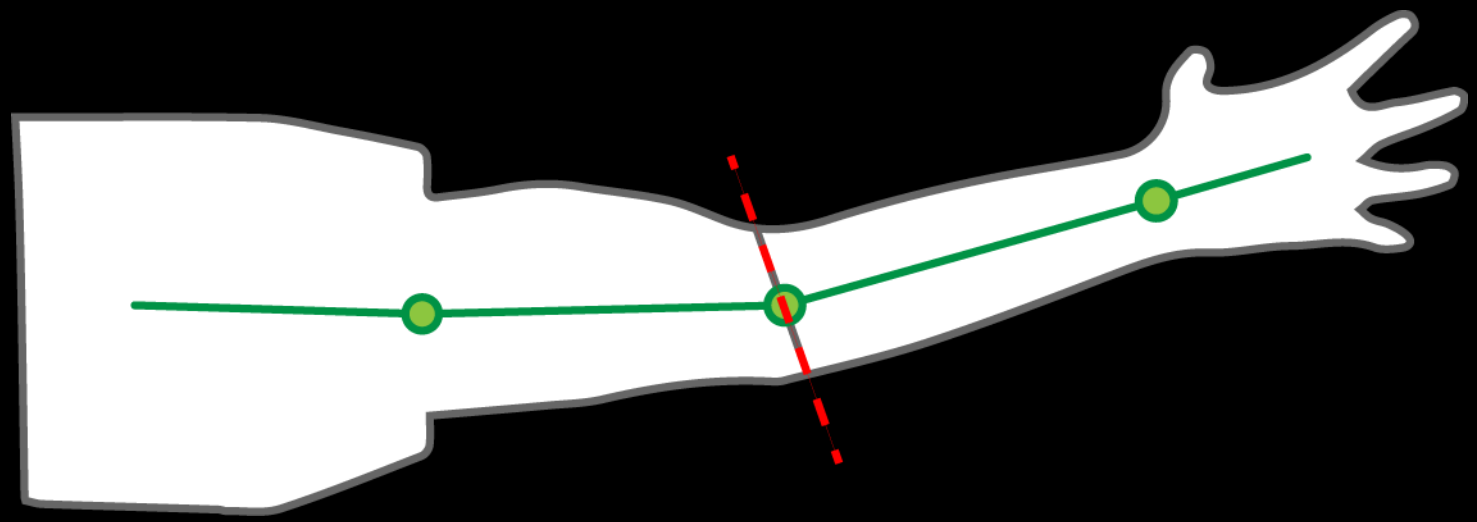
Rotational Constraints Validity

- Check that ball does not fall out of its socket:
  - Compute convex hull of inside surface of the sculpted socket
  - Verify that the ball's centre is within the hull

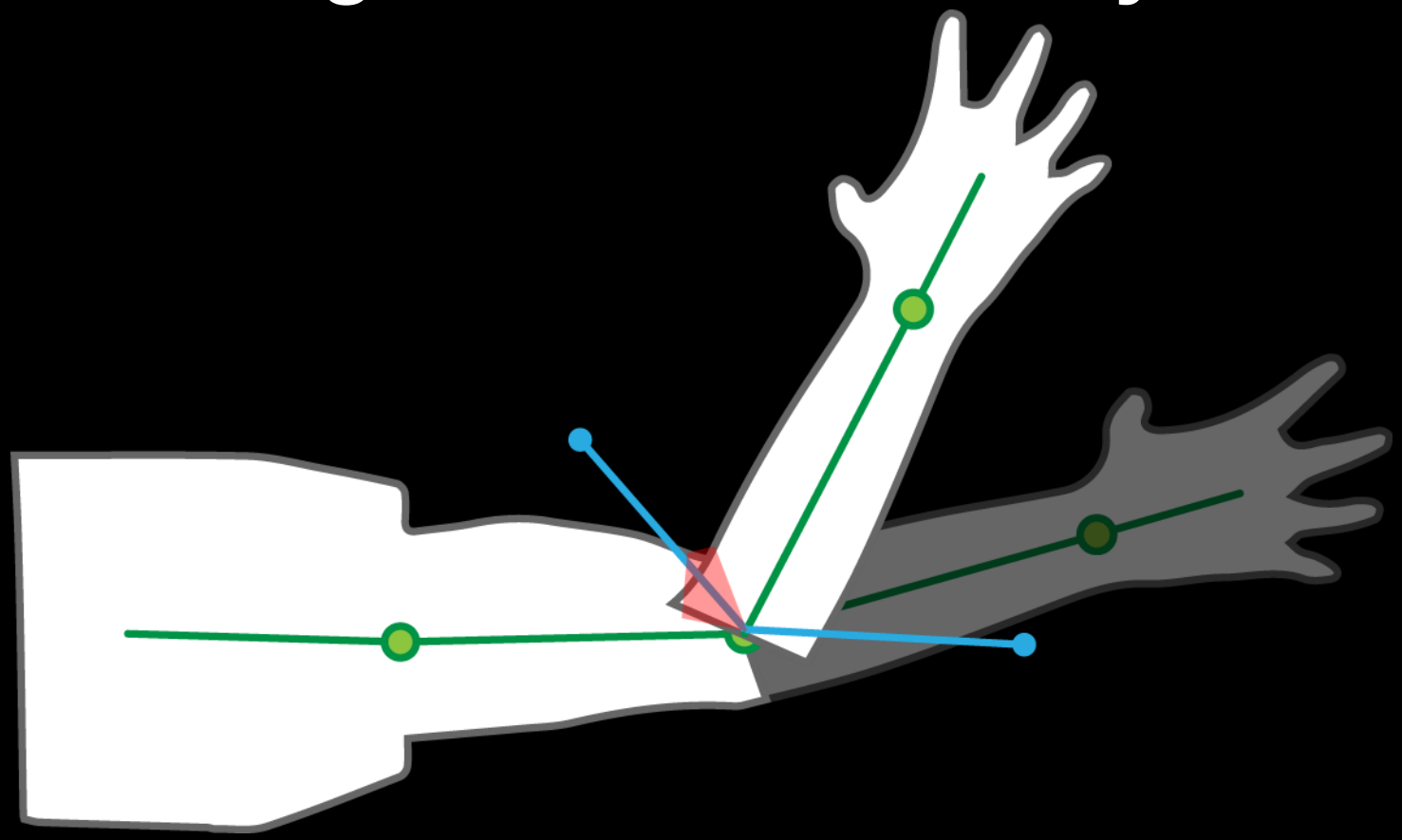
Removing Excess Geometry



Removing Excess Geometry



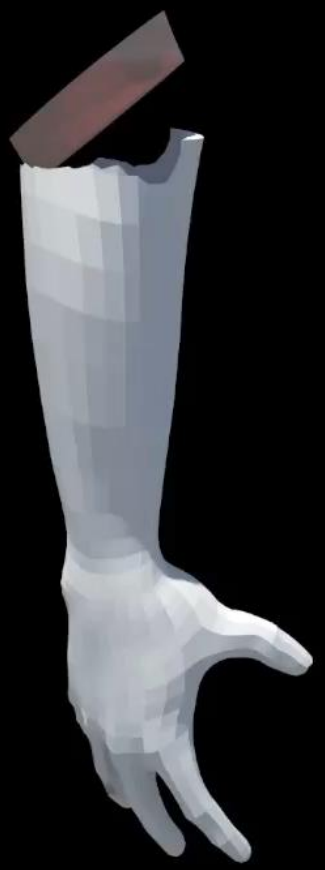
Removing Excess Geometry



Removing Excess Geometry

- Geometry is rotated along the trajectory of the user's specification

- Excess geometry is removed by CSG subtraction

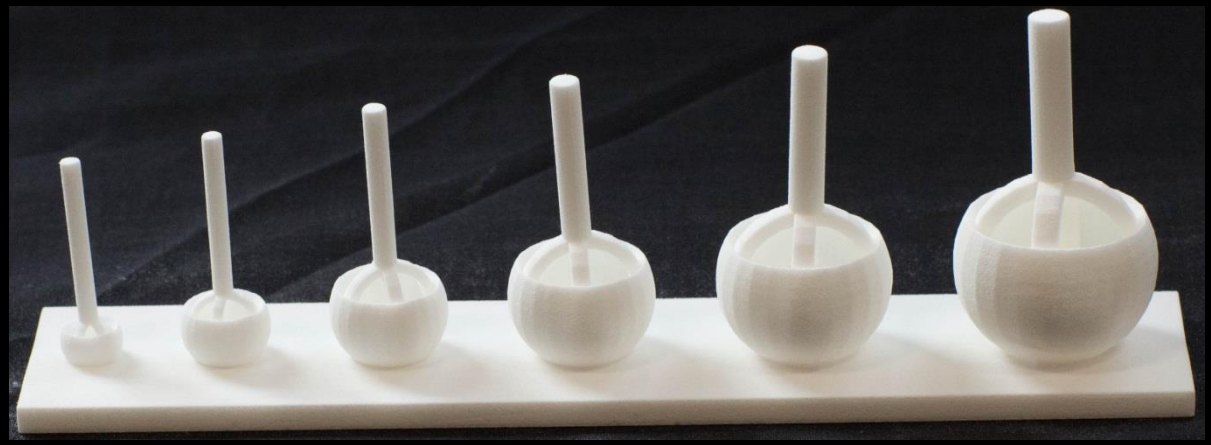


3D Printing Technologies

- Selective Laser Sintering
- Polyjet
- Fused Deposition Modelling

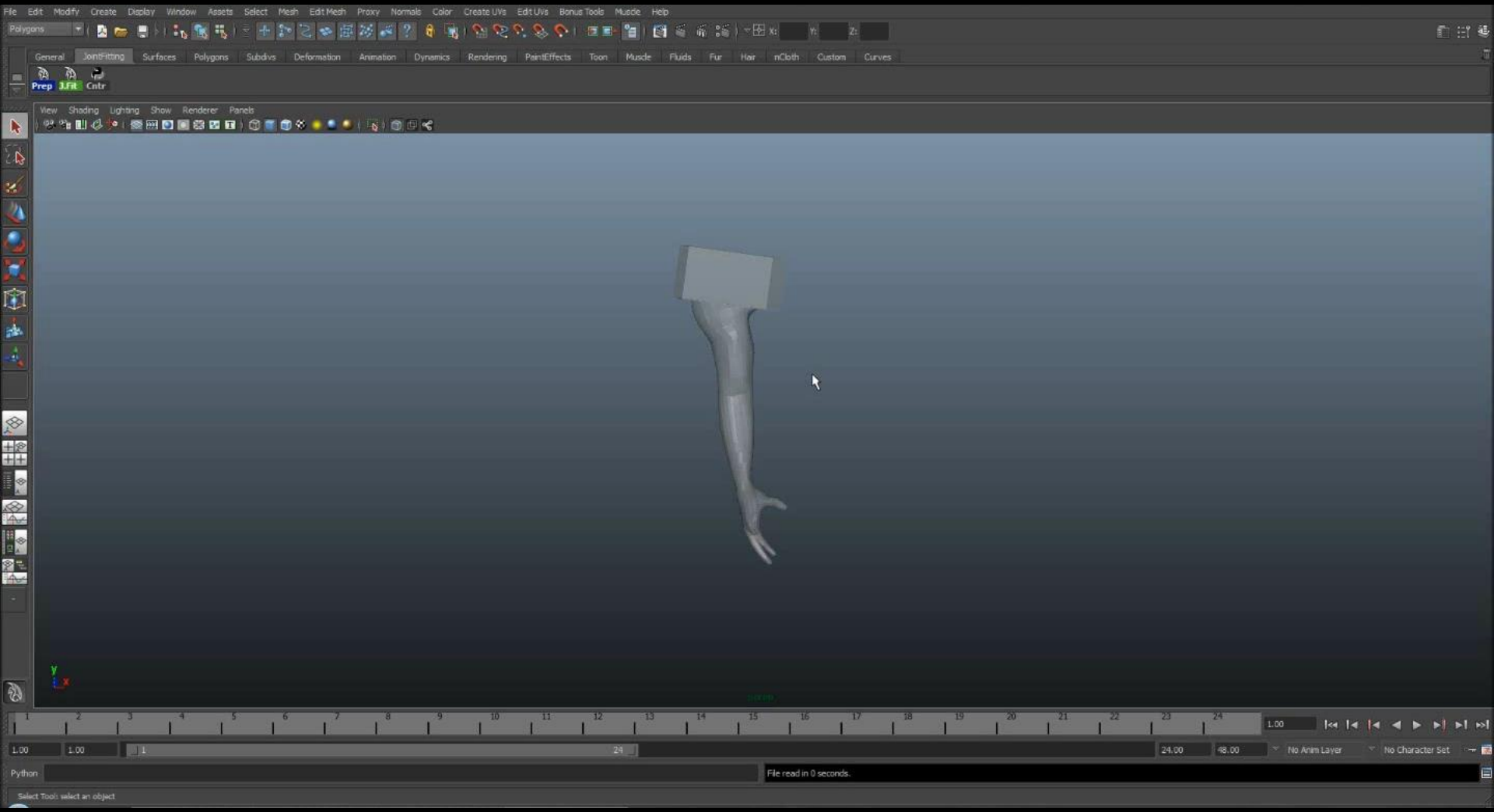
Calibration

- Calibration sets printed to determine printer and material parameters:
  - Width of the friction bands
  - Minimal gap size (tolerance)
  - Minimal joint size (shown below)



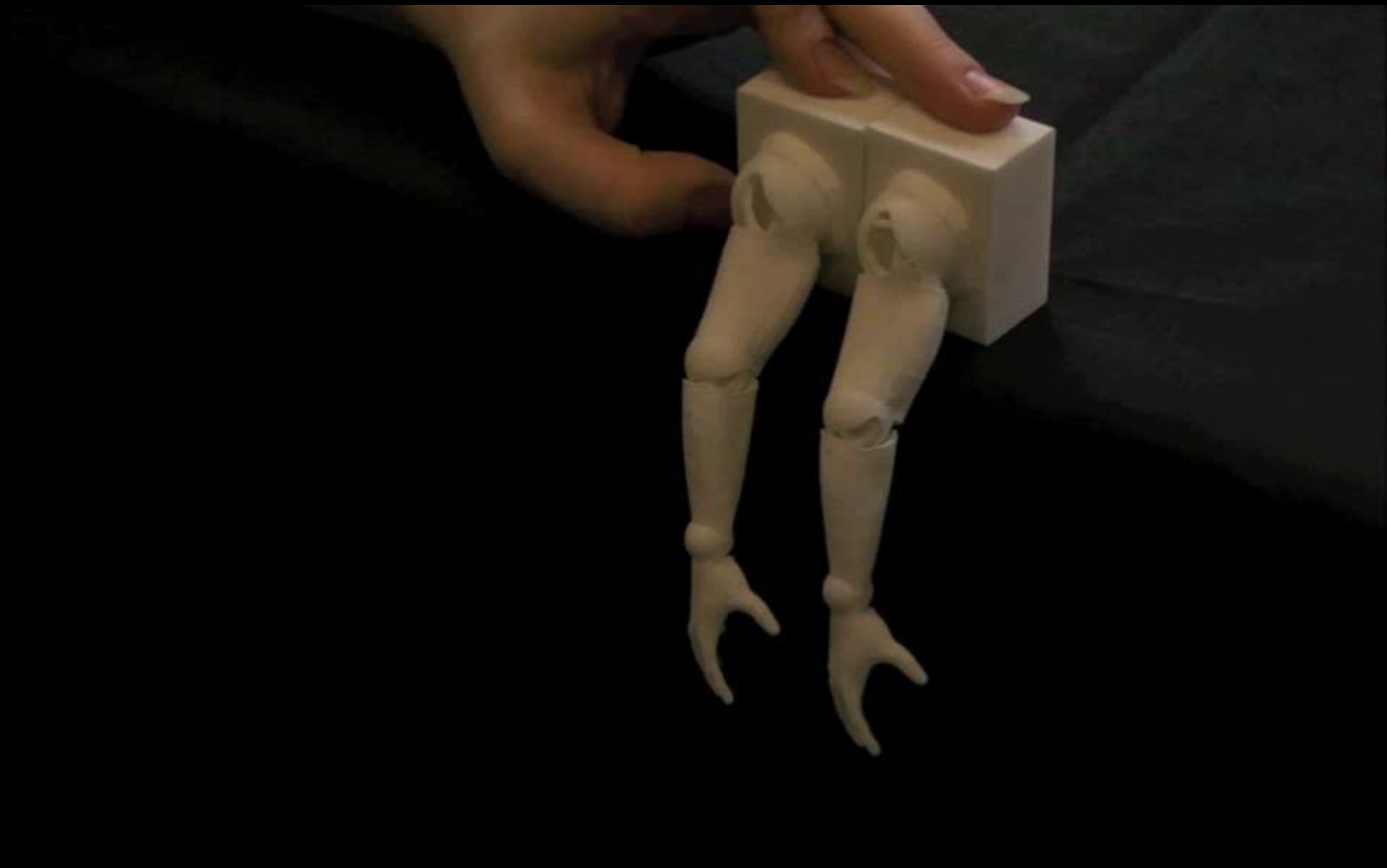
Results

Workflow


File Edit Modify Create Display Window Assets Select Mesh Edit Mesh Proxy Normals Color Create UVs Edit UVs Bonus Tools Muscle Help
Polygons
General JointFitting Surfaces Polygons Subdvs Deformation Animation Dynamics Rendering PaintEffects Toon Muscle Fluids Fur Hair nCloth Custom Curves
Prep 3.Fit Cntr
View Shading Lighting Show Renderer Panels
Python
File read in 0 seconds.
Select Tool: select an object

Example Models

Friction vs. No-Friction



Limitations

- Material Strength
- Twist
- CSG robustness

Conclusion

- Derived joint template that:
  - Incorporates friction without assembly
  - Controllable rotational constraints
  - Support material drainage
- Calibration sets
- Intuitive joint fitting pipeline


Thank you!
Questions?