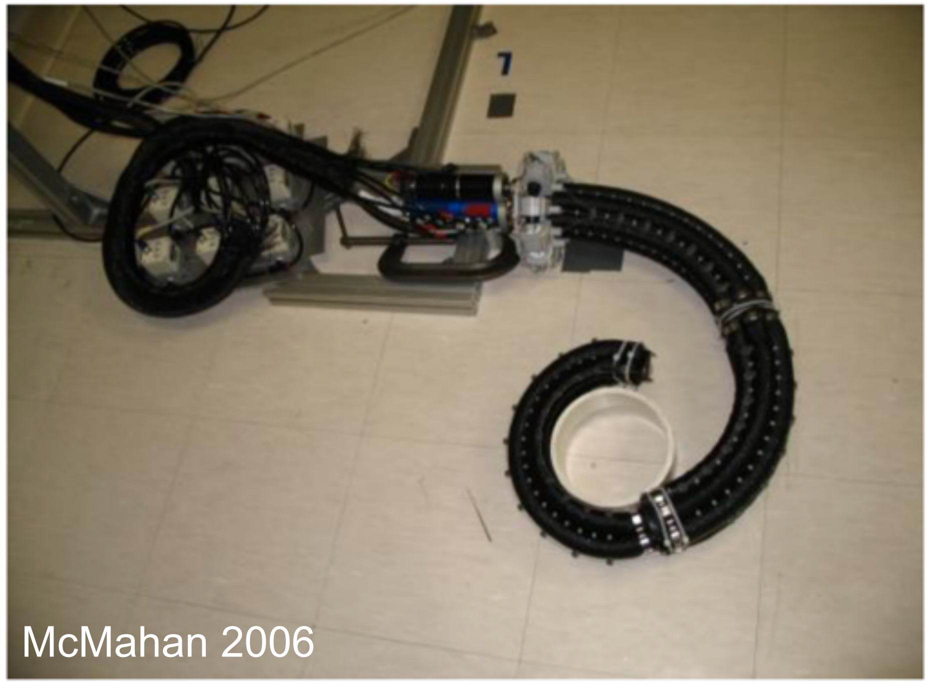
Soft Robots for Humanity

Allison M. Okamura

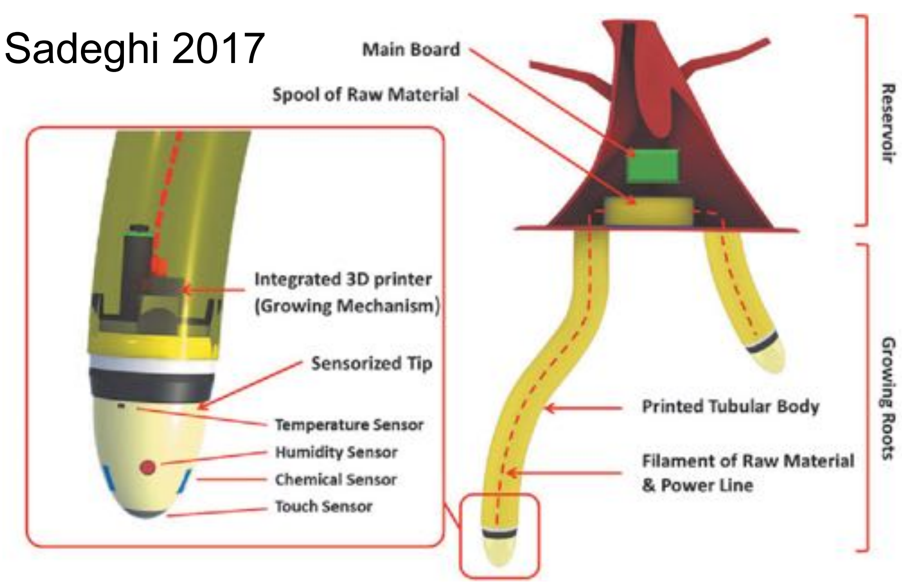
Department of Mechanical Engineering
Stanford University
http://charm.stanford.edu

Continuum Robots

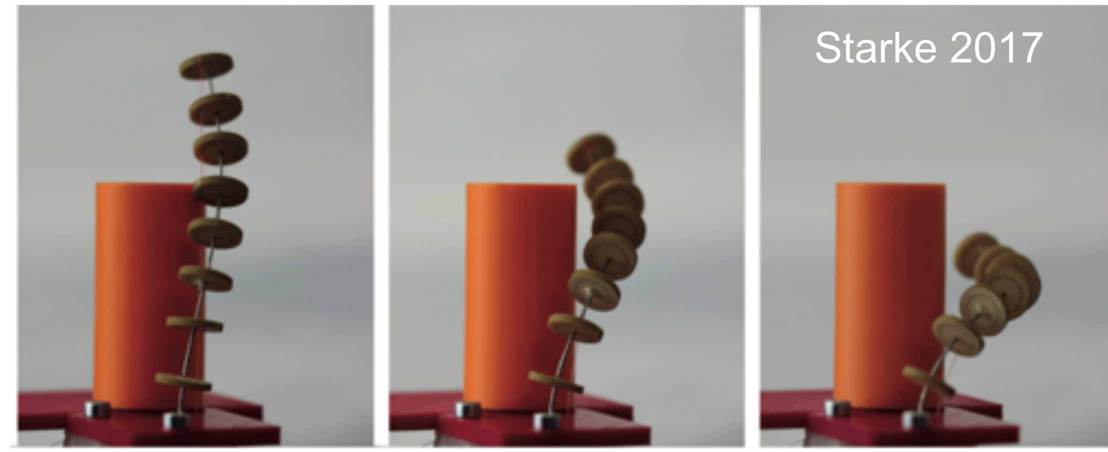

Marchese 2016


McMahan 2006

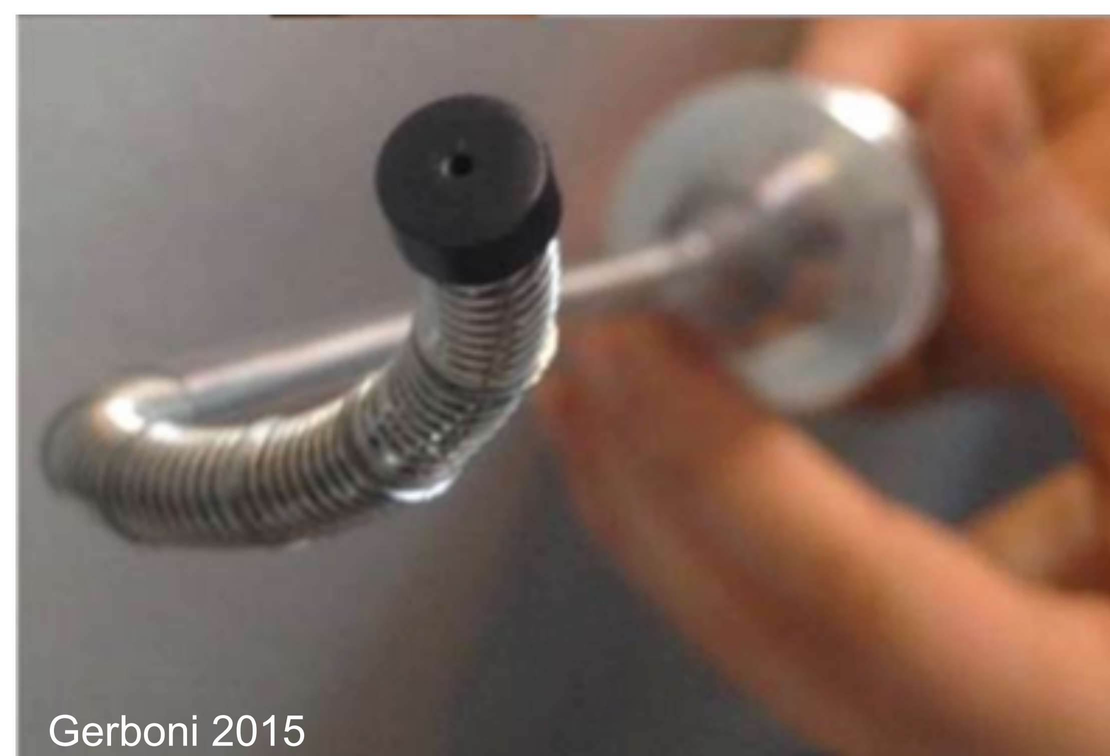
Sadeghi 2017



Tsukagoshi 2011

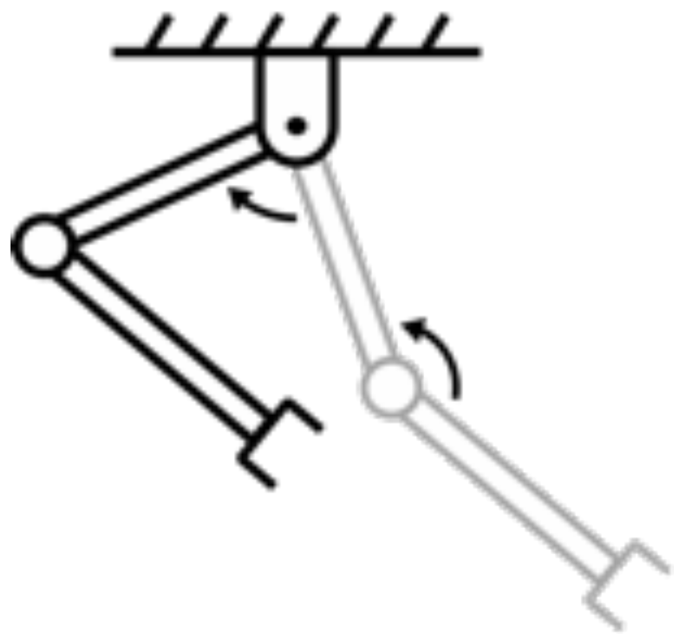

Starke 2017


Rucker 2011

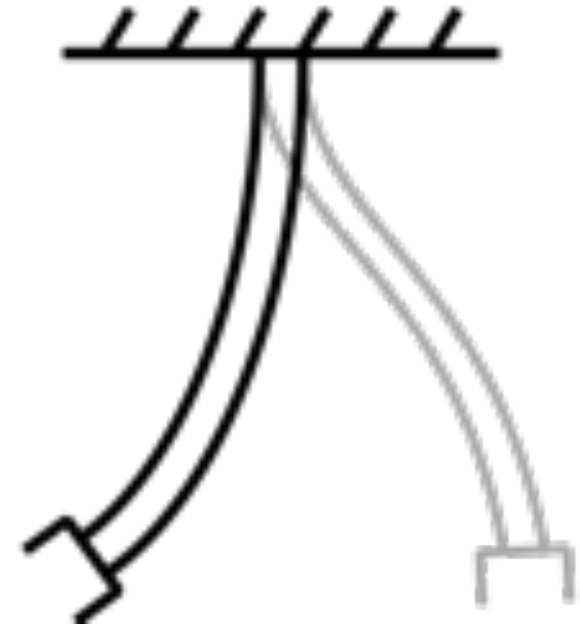

Gerboni 2015

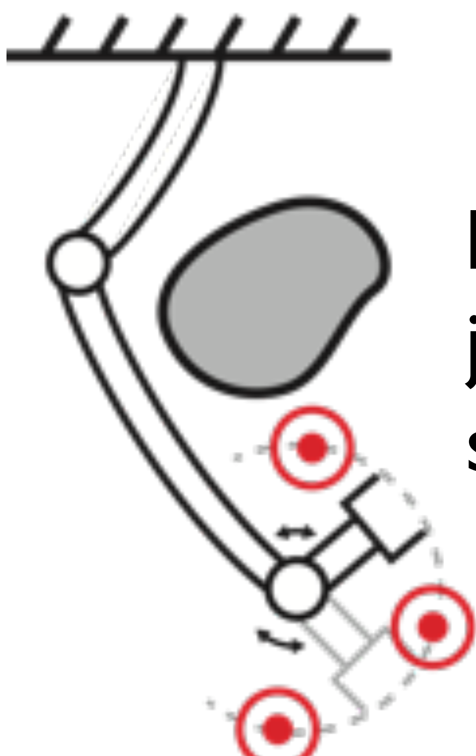
Best of Both Worlds?

Hard Robots



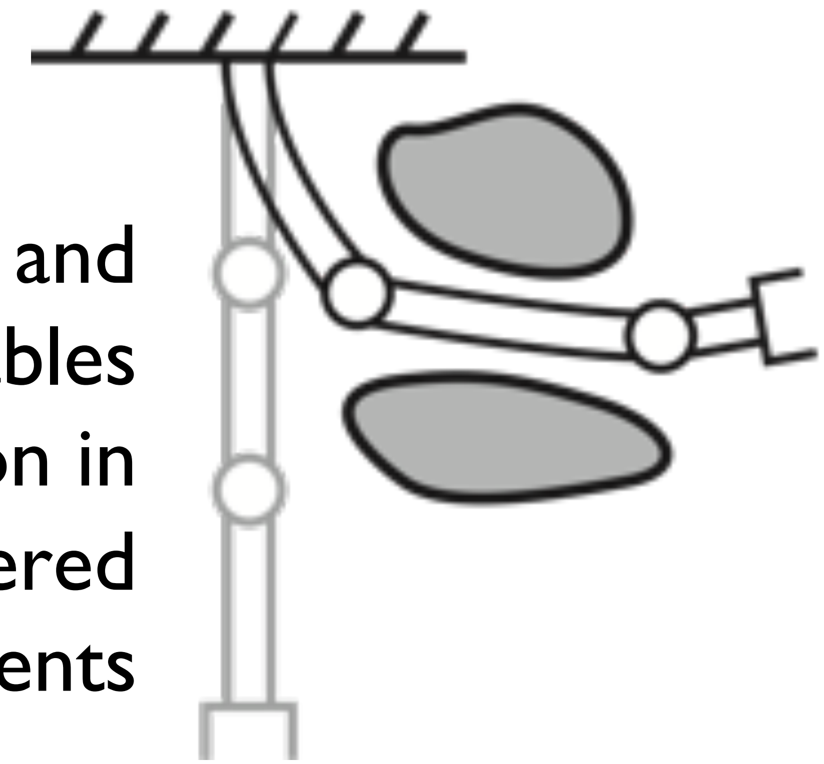
Soft Robots





localized joints allow sharp turns

bending and softness enables safe navigation in cluttered environments



A Continuum of Continuum Robots

Material:	Stiff	Flexible	Flexible
Structure:	Flexible	Flexible→Stiff	Stiff

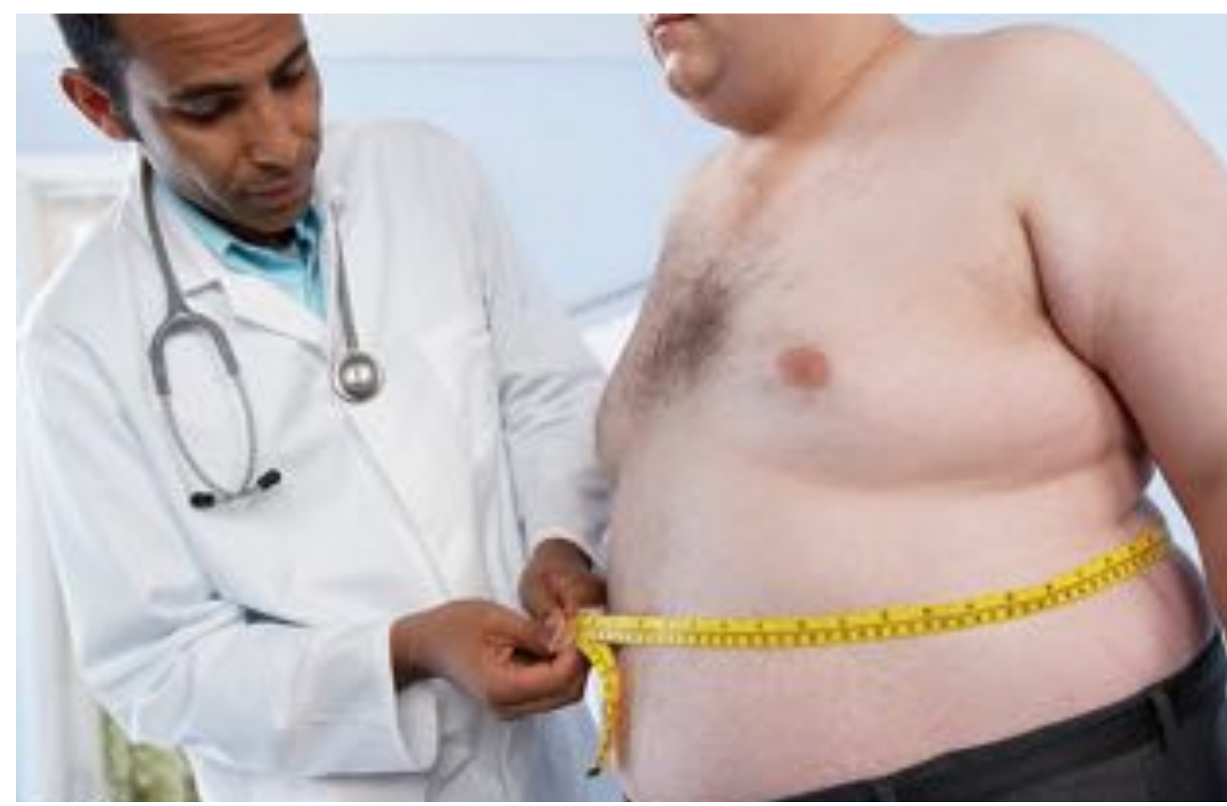
Soft, steerable, patient-specific medical robots

Tania Morimoto
(UCSD)

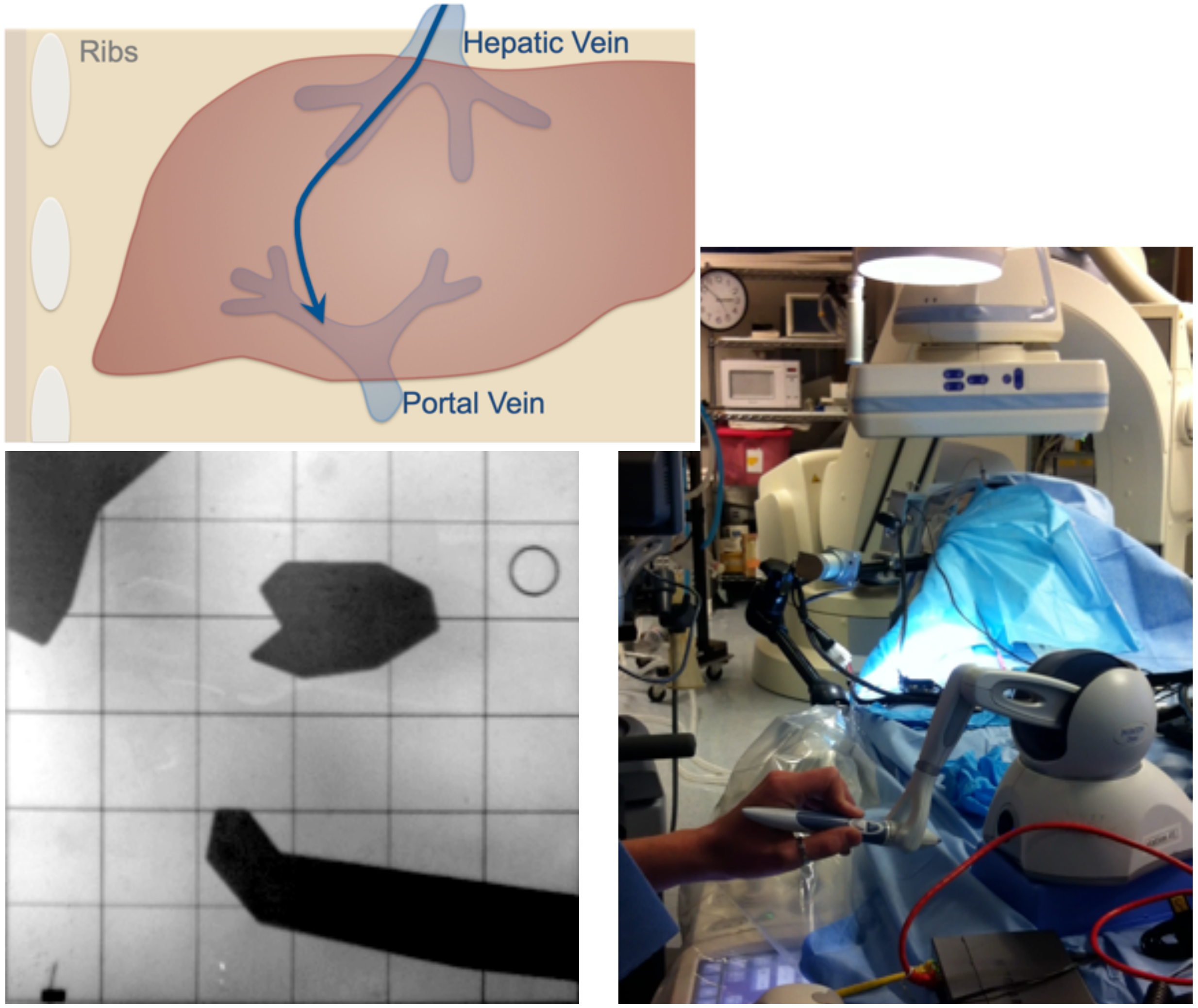
Supported by: National Institutes of Health, National Science Foundation Graduate Fellowship Program

Template Robotic Surgical Systems

Marginalized Patient Populations



Steerable Needles

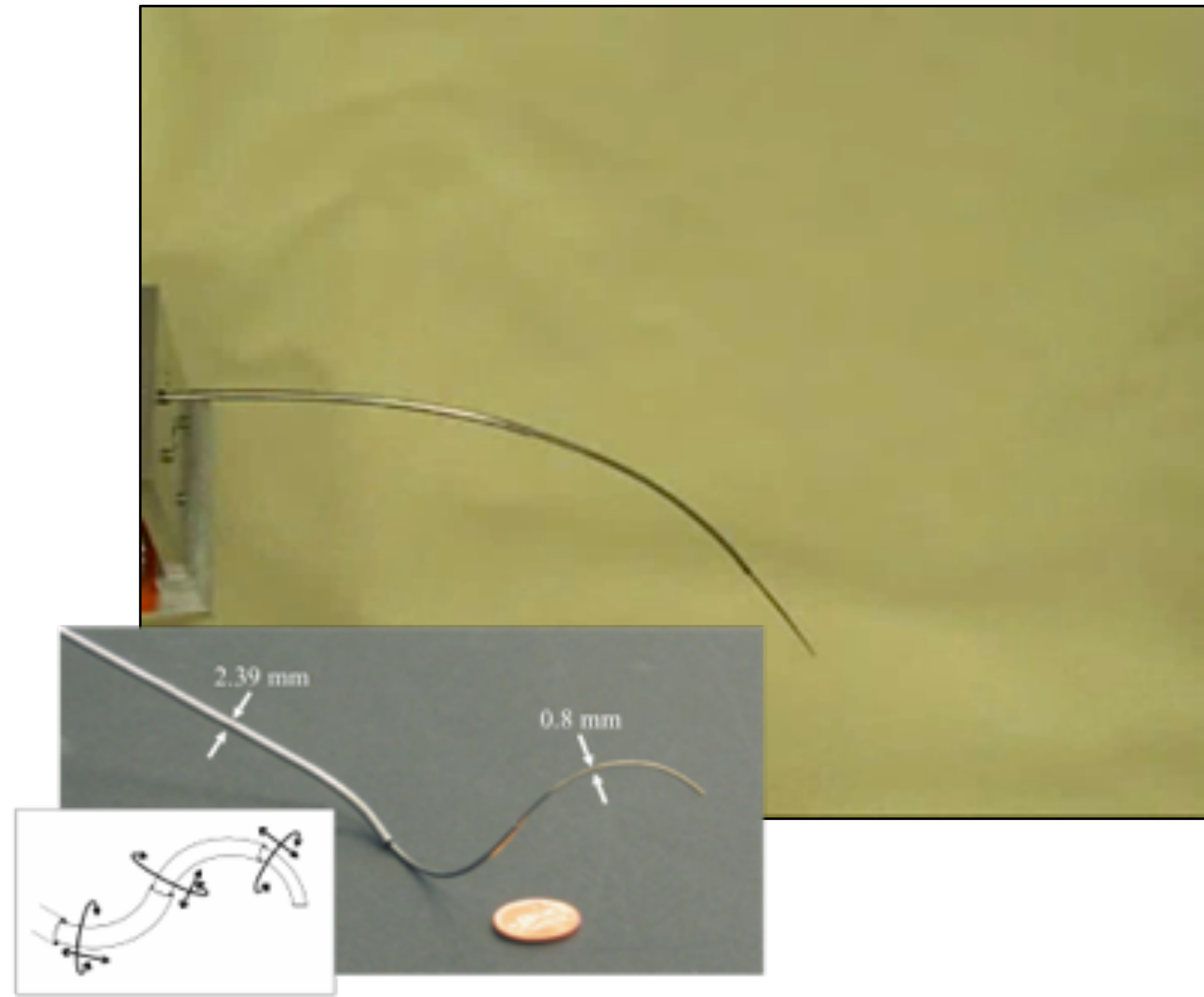


- Asymmetric tip results in bending when inserted into tissue
- Needle flexibility allows reorientation of tip

Webster et al. IJRR 2006, Reed et al. RAM 2011, Majewicz et al. WHC 2013, Adebar et al. TBME 2014, Gerboni et al. RAL 2017

Image and video courtesy of Ann Majewicz Fey, UT Austin

Concentric Tube Robots

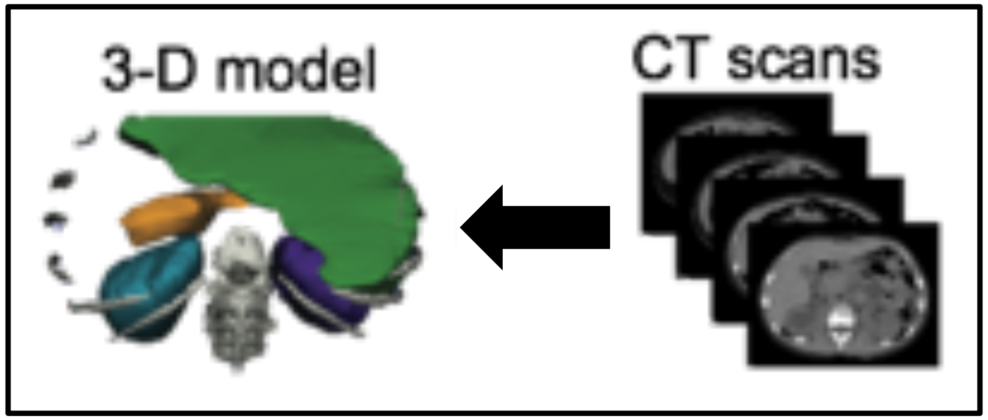


- Hollow, pre-curved tubes fit concentrically inside each other
- Relative insertion and rotation results in bending

Webster et al. IROS 2006, Sears et al. IROS 2006, Webster et al. ICRA 2008, Dupont et al. TRO 2010, Bedell et al. ICRA 2011

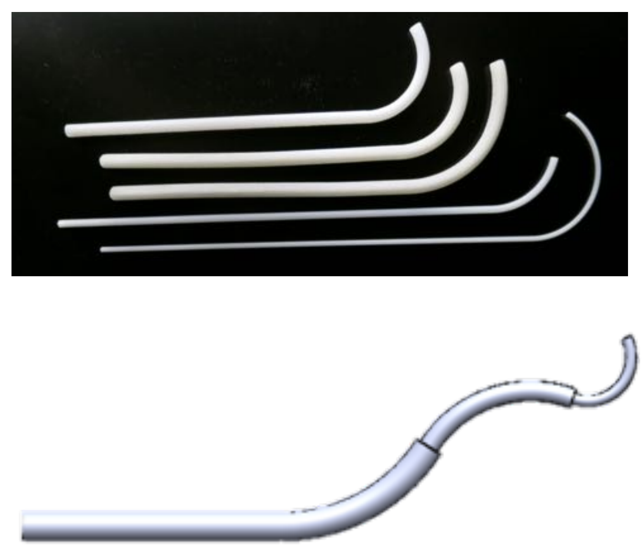
Image and video courtesy of Robert Webster III, Vanderbilt Univ.

Patient-Specific Design Workflow

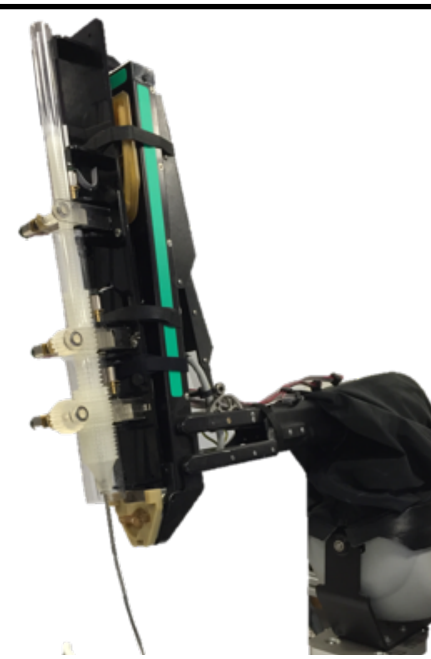


Patient is a
9-year-old boy
(disclaimer: this is
not the patient)

Design



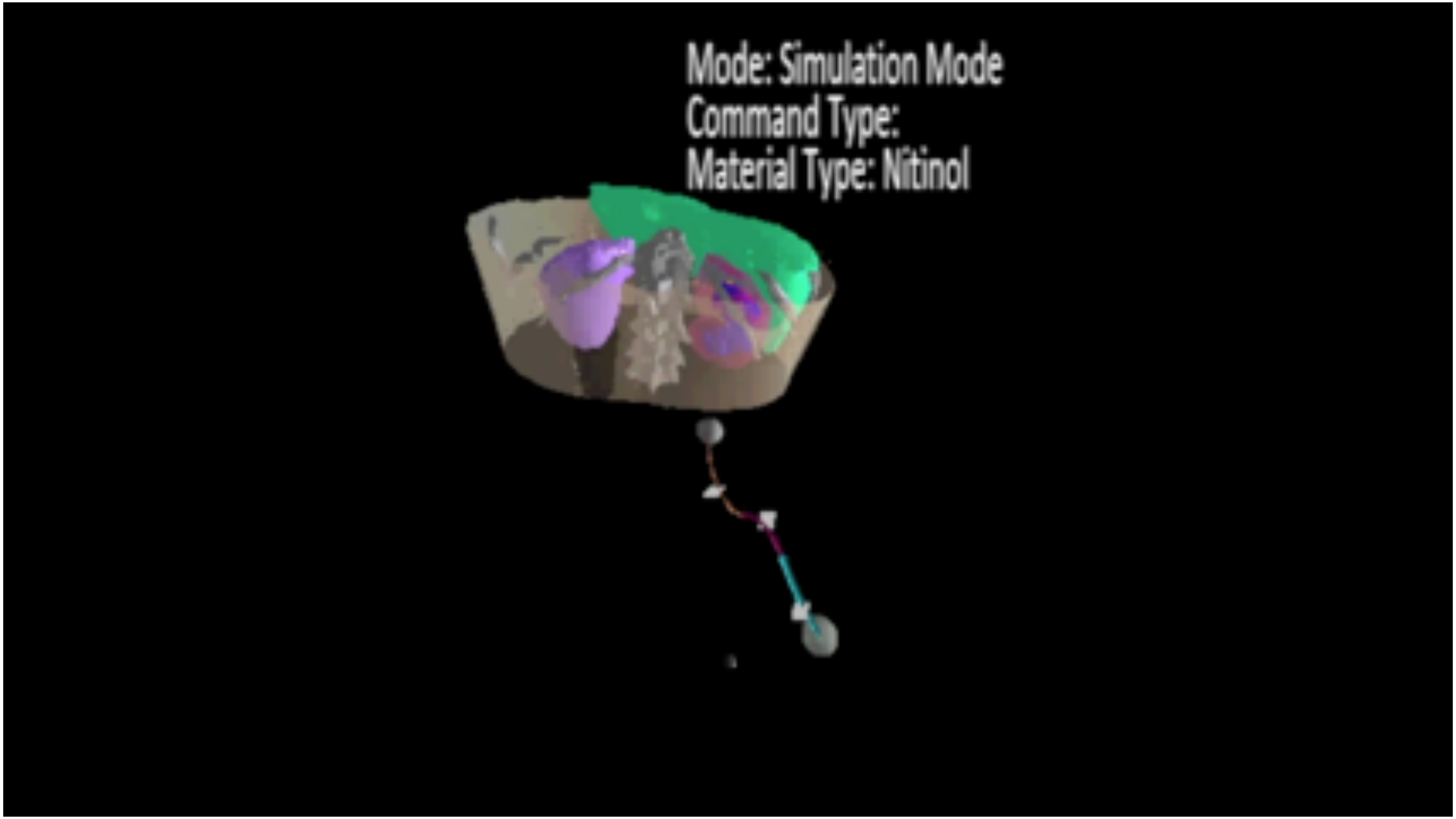
Fabricate



Drive

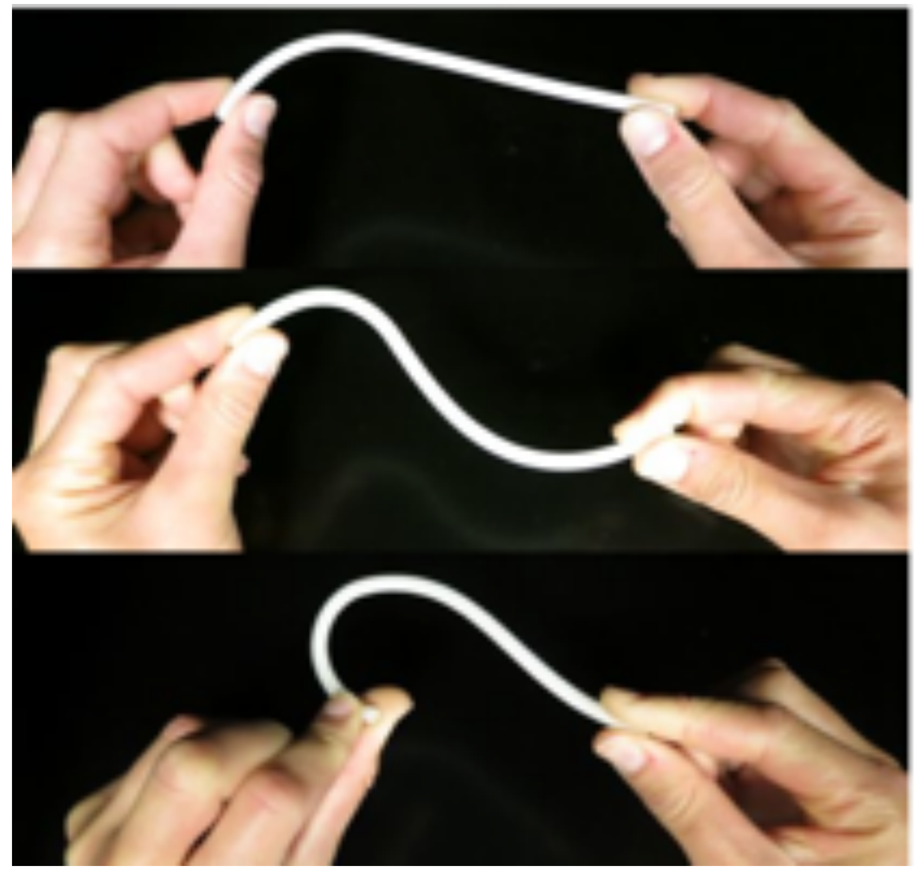
Initialize Concentric Tube Robot Design

Simulate Concentric Tube Robot

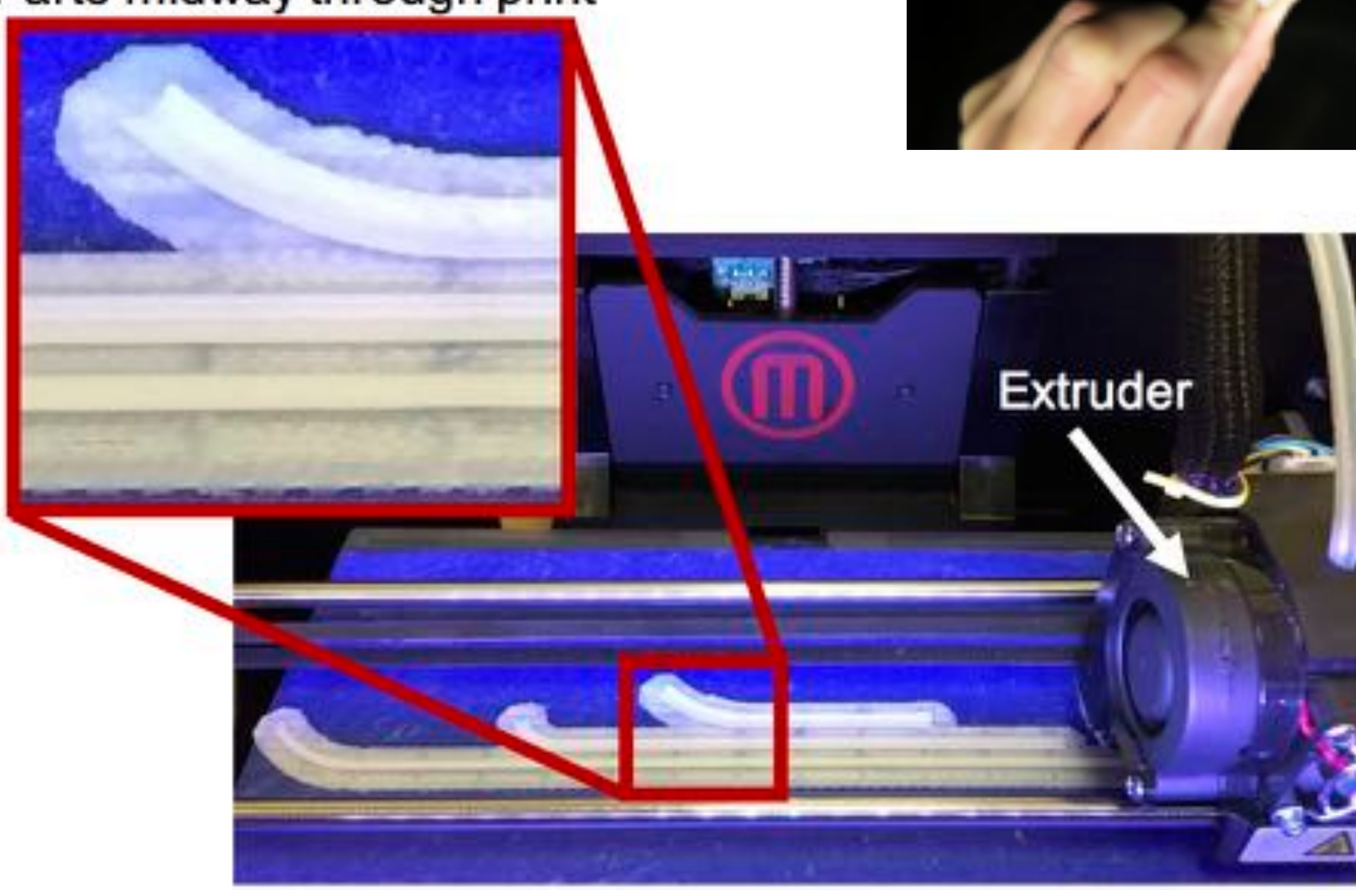


3D-Printed Polycaprolactone (PCL)

- Biodegradable polyester
- Often used for sutures and long-term implantable devices
- 3D print on Makerbot

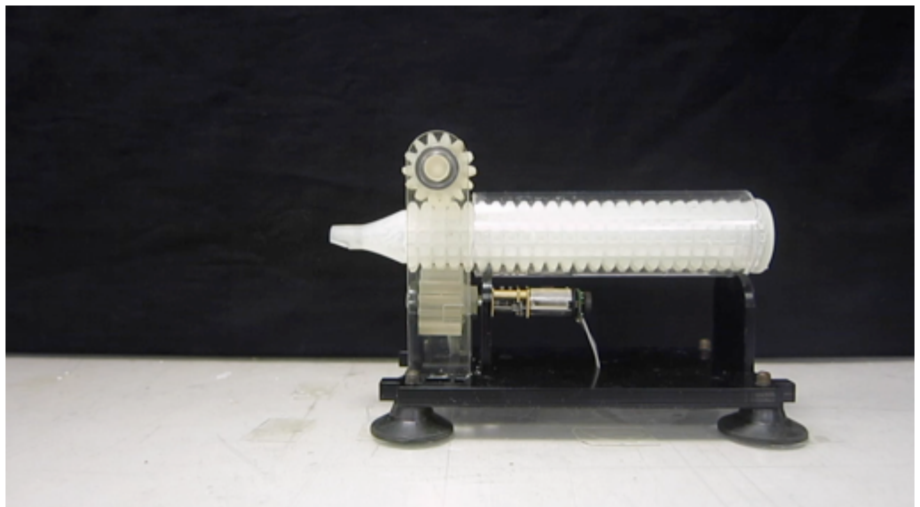


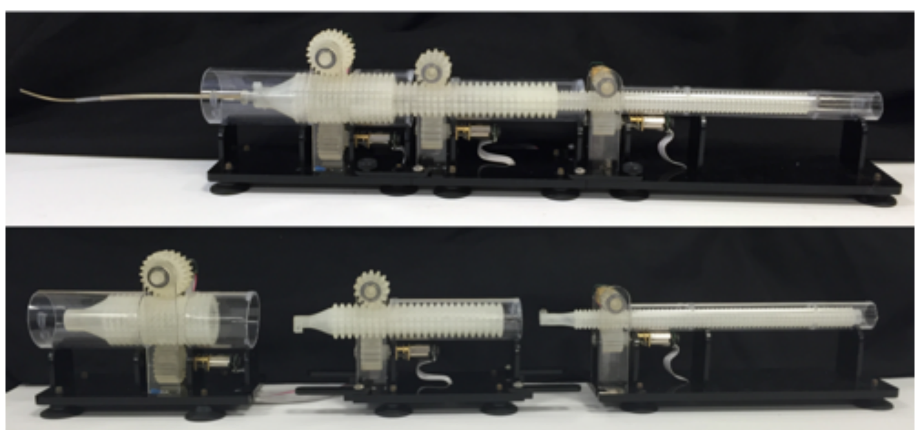
Parts midway through print

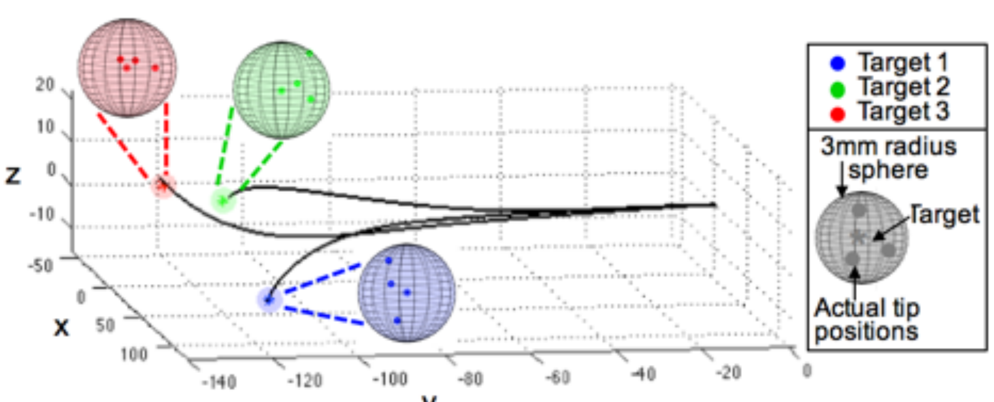


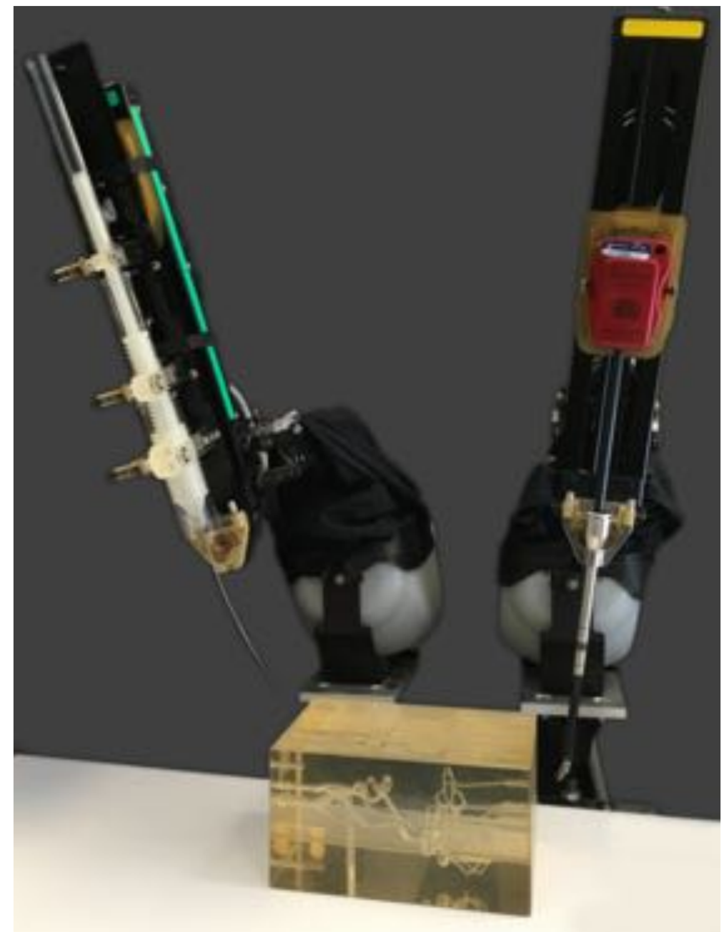
Morimoto et al. TRO 2016

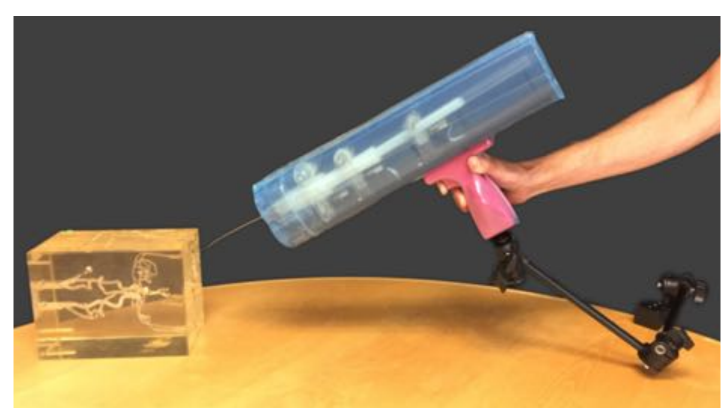
Actuation System





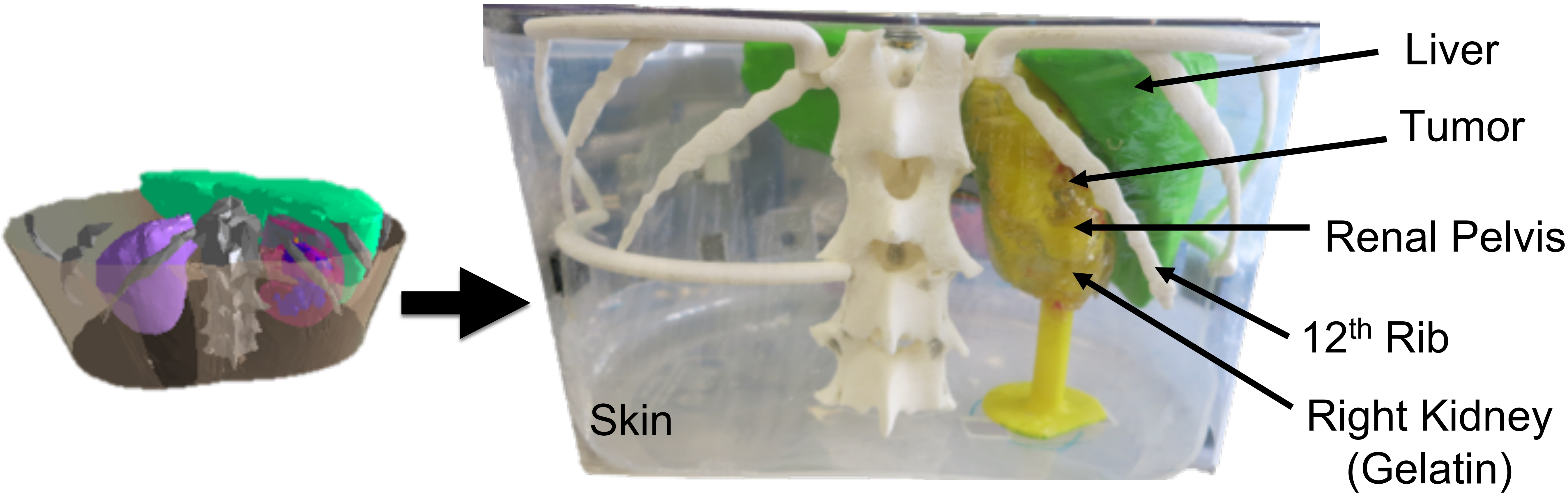


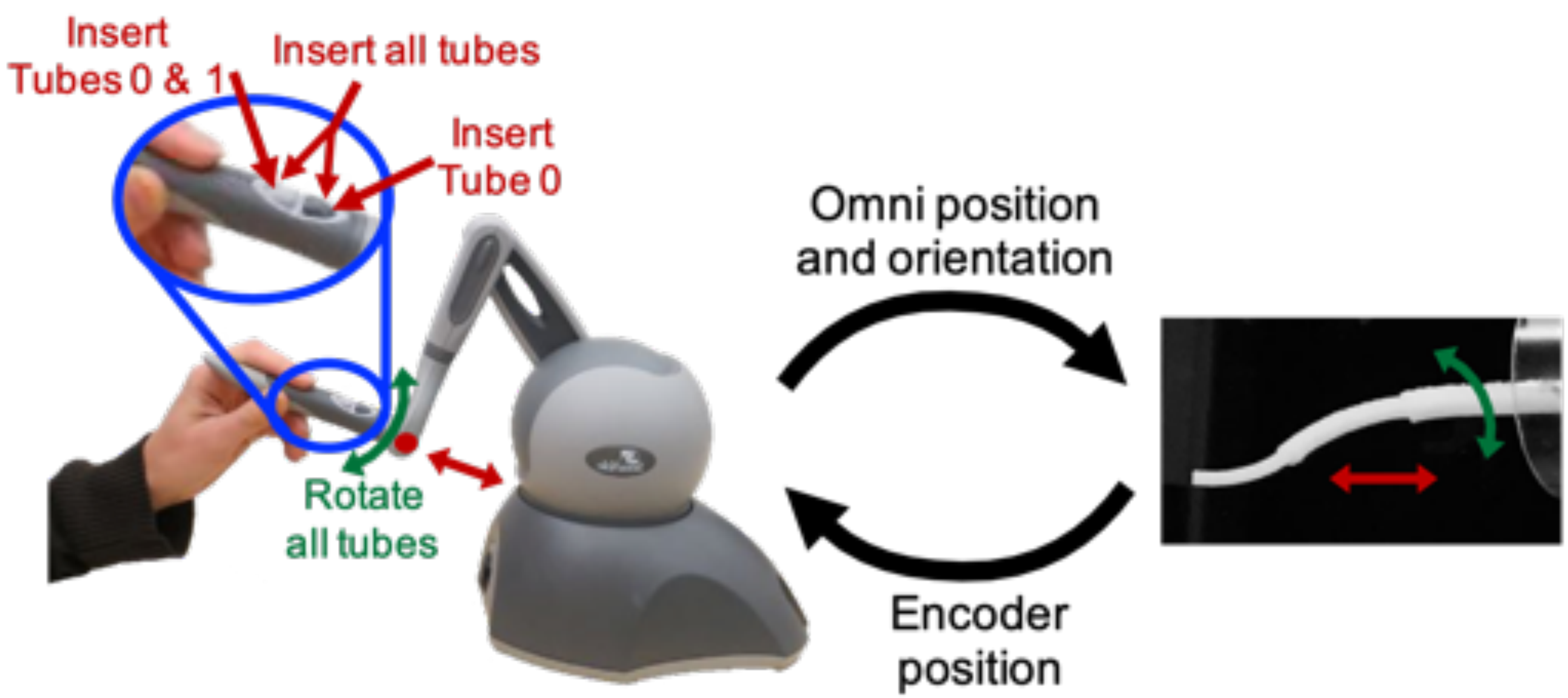




Morimoto et al. RA-L 2017, Morimoto et al. Annals BME 2018

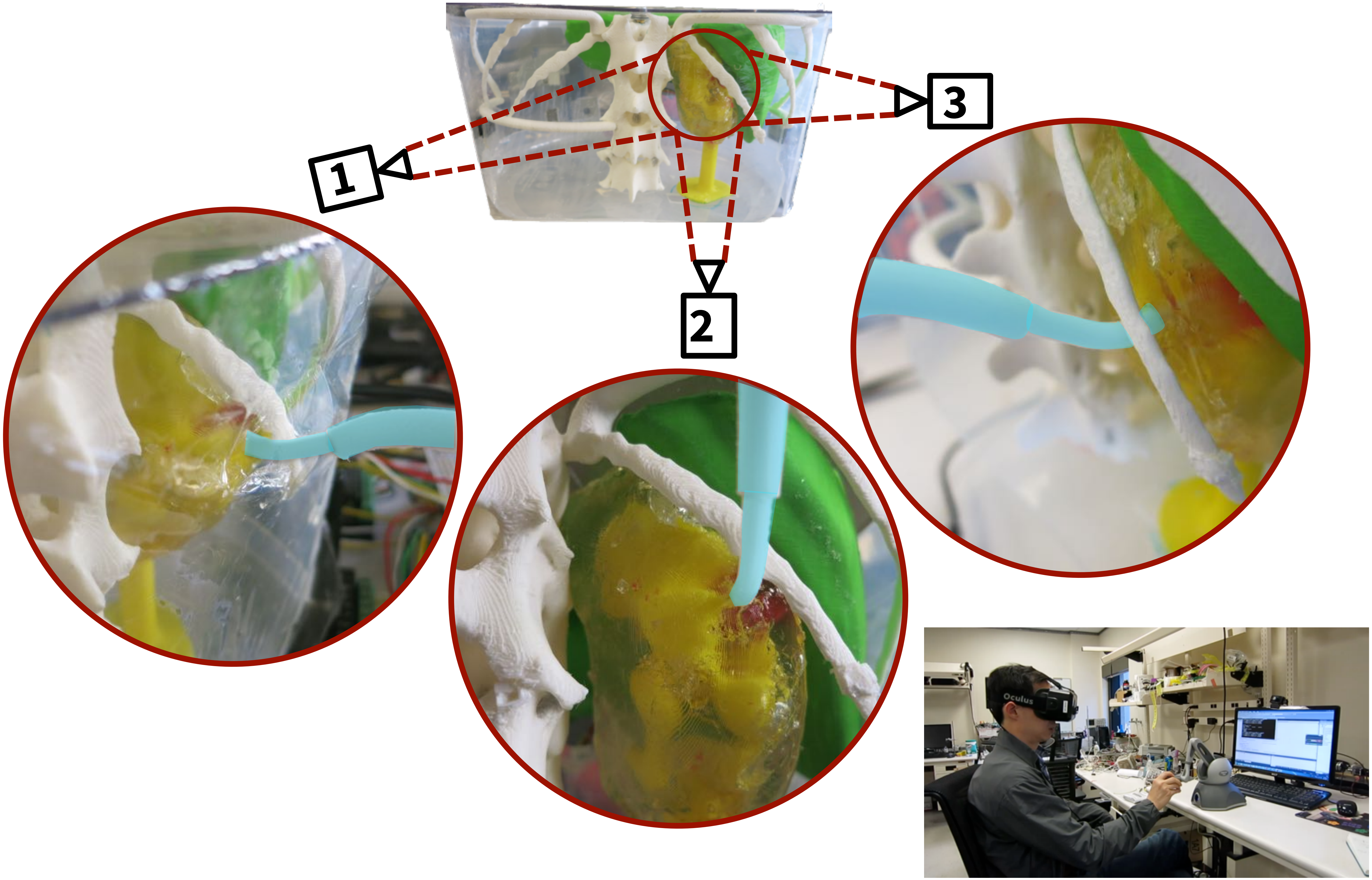
System Demonstration





Morimoto et al. 2018

System Demonstration



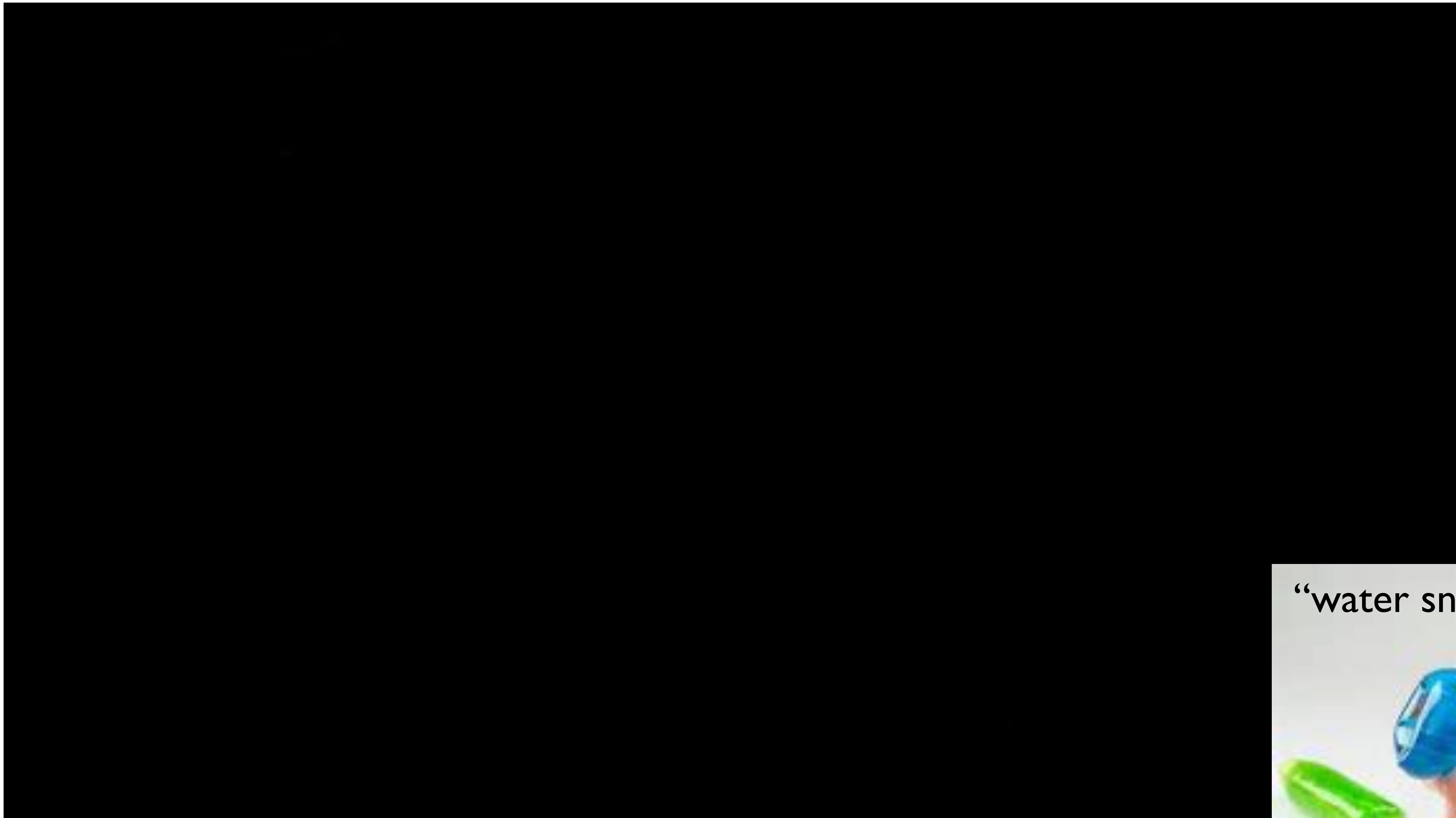
Robots that grow by tip eversion

Elliot Hawkes
(UCSB)

Laura Blumenschein
(Purdue)

Joey Greer
(Facebook)

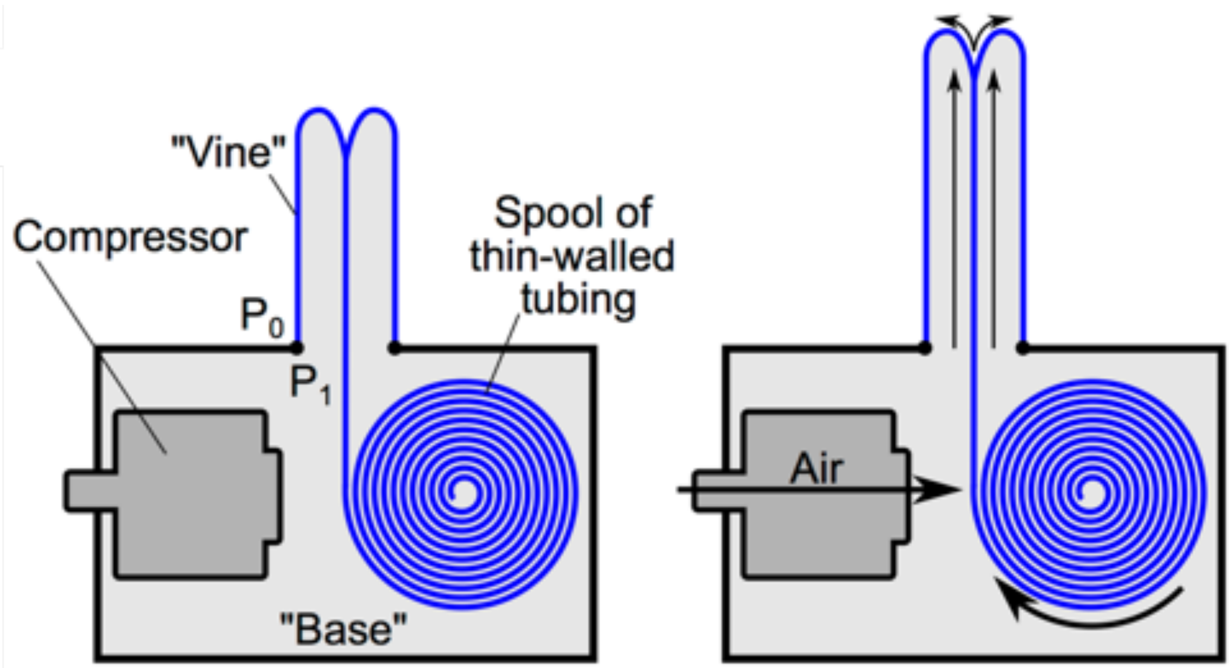
Supported by: National Science Foundation, Air Force Office of Scientific Research
(With Jonathan Fan and Sean Follmer)

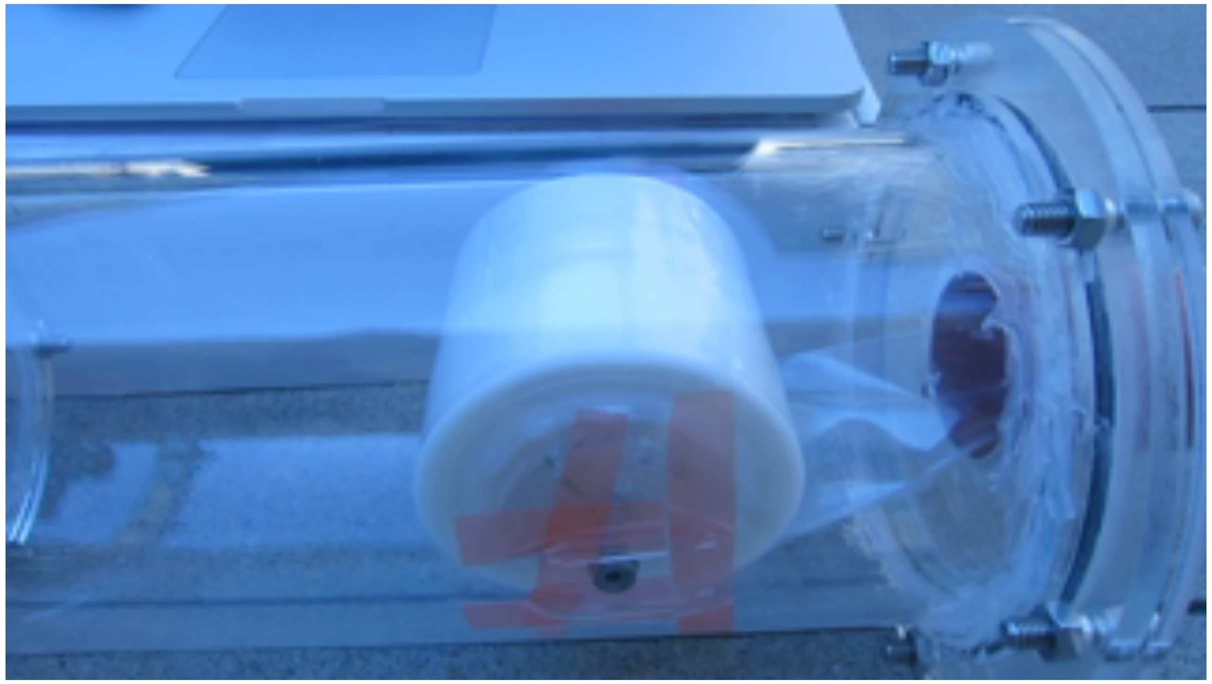


Passing flexible plastic material to the “growth” site is **reversible** and can be **very fast** (up to 10 m/s measured to date)

Hawkes et al. Science Robotics 2017 (prior: Orekhov et al. IROS 2010, Tsukagoshi et al. IJAT 2011, Mishima et al. FSR 2003)

Extremely large change in length is achieved by using **air** for volume change and **thin polymer membranes** for surface area change

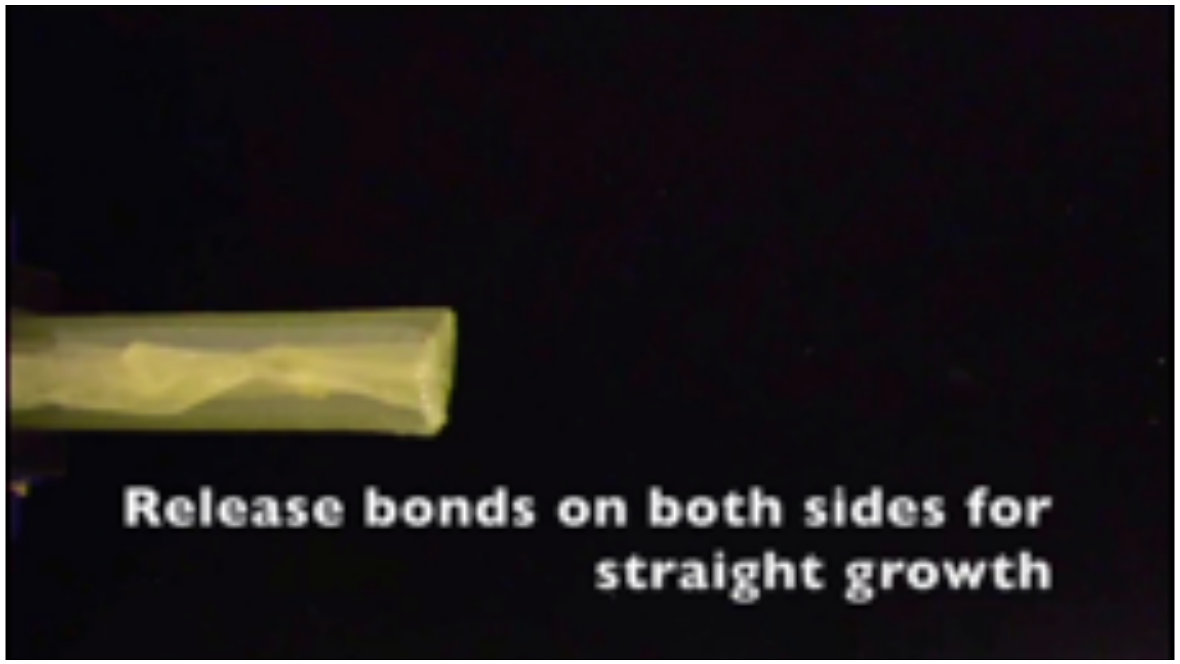




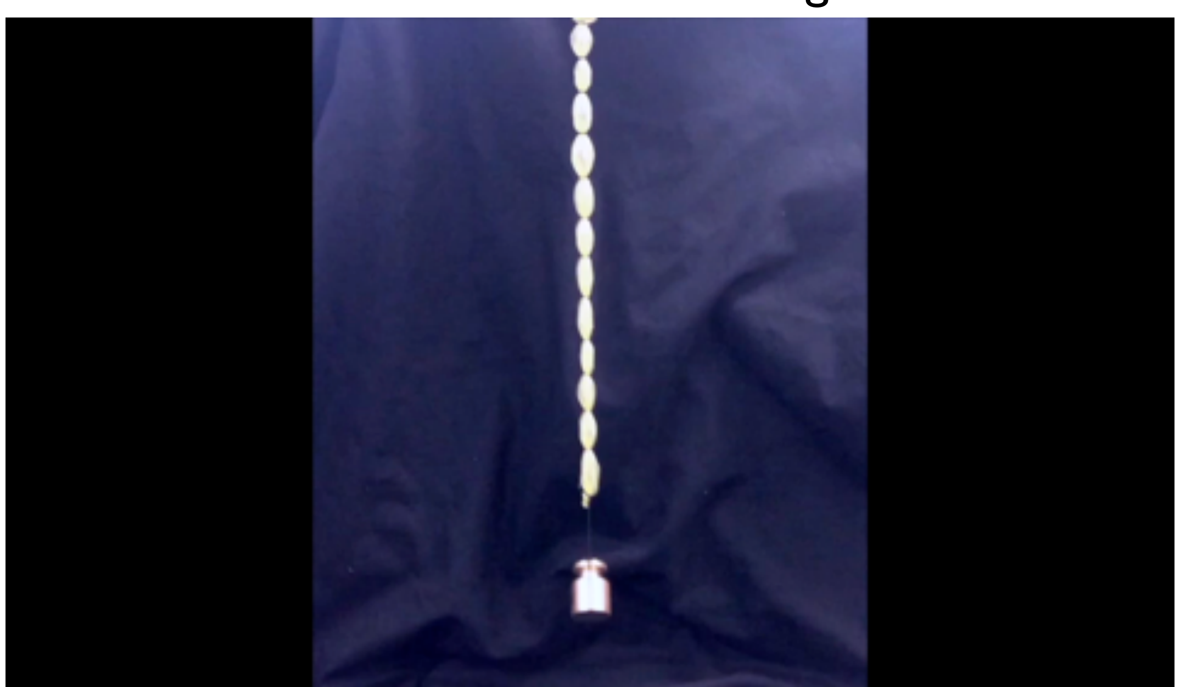
Blumenschein et al. Living Machines 2017

Control of growth direction can also be achieved through **activator/actuator routing**

permanent direction change

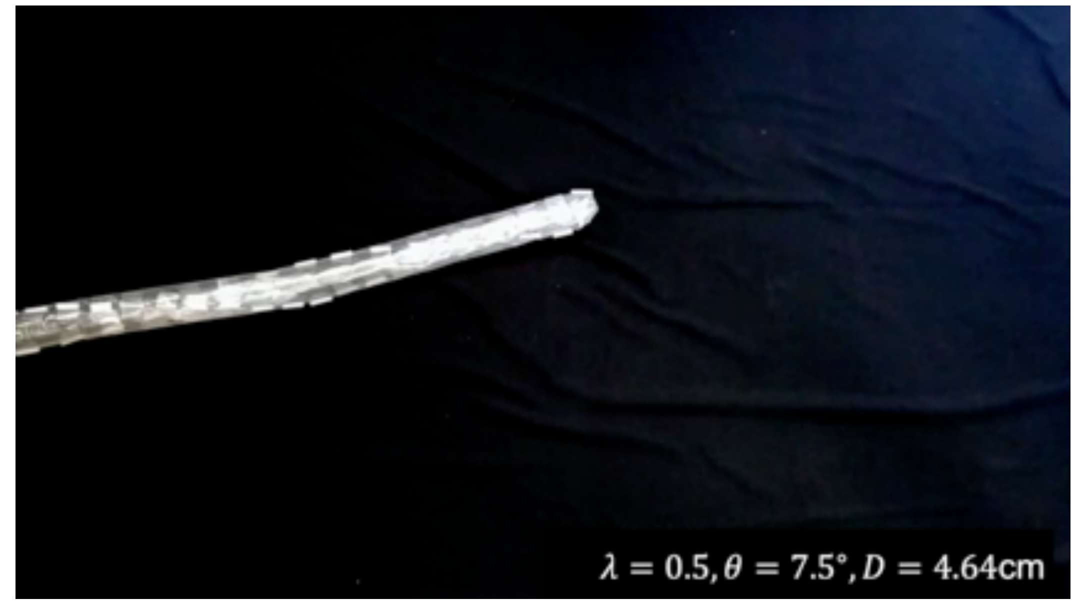


reversible direction change



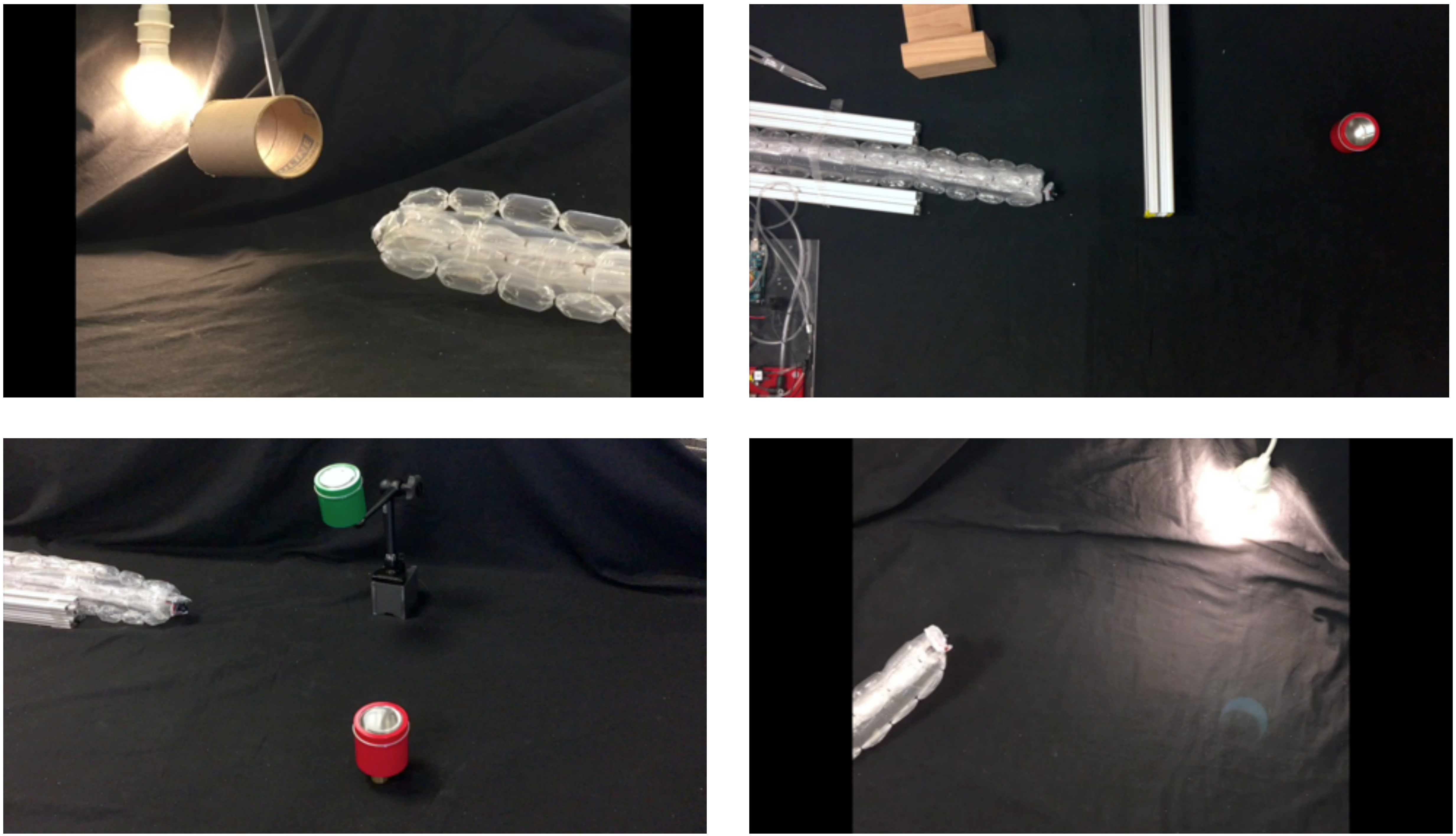
Greer et al. ICRA 2017, SoRo 2019

helical routing



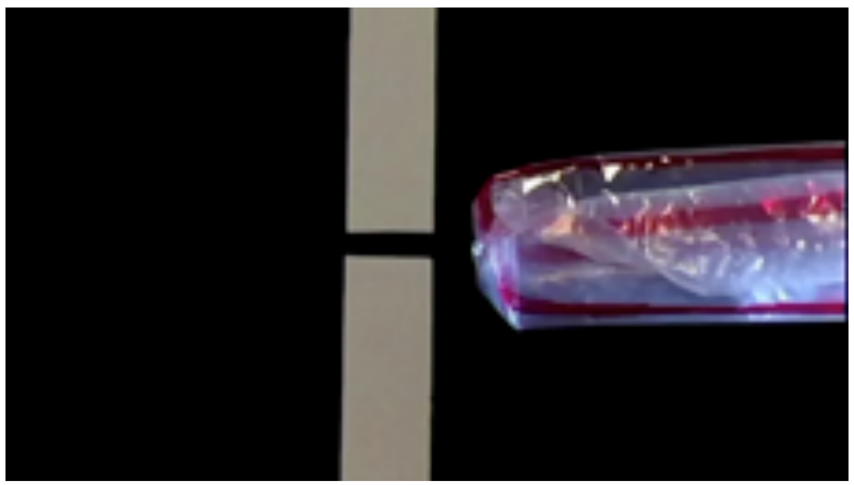
Blumenschein et al. RoboSoft 2018, RA-L 2020, ArXiv 2020

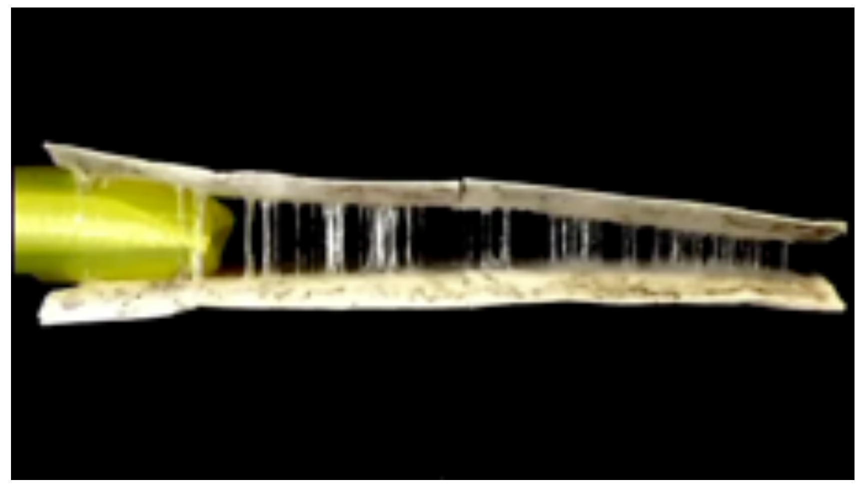
Control of growth direction can be achieved **actively** using sensor feedback

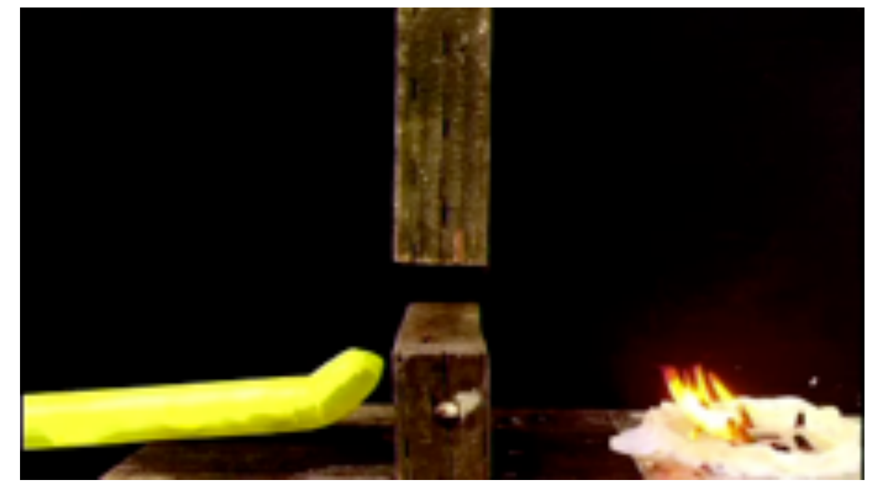


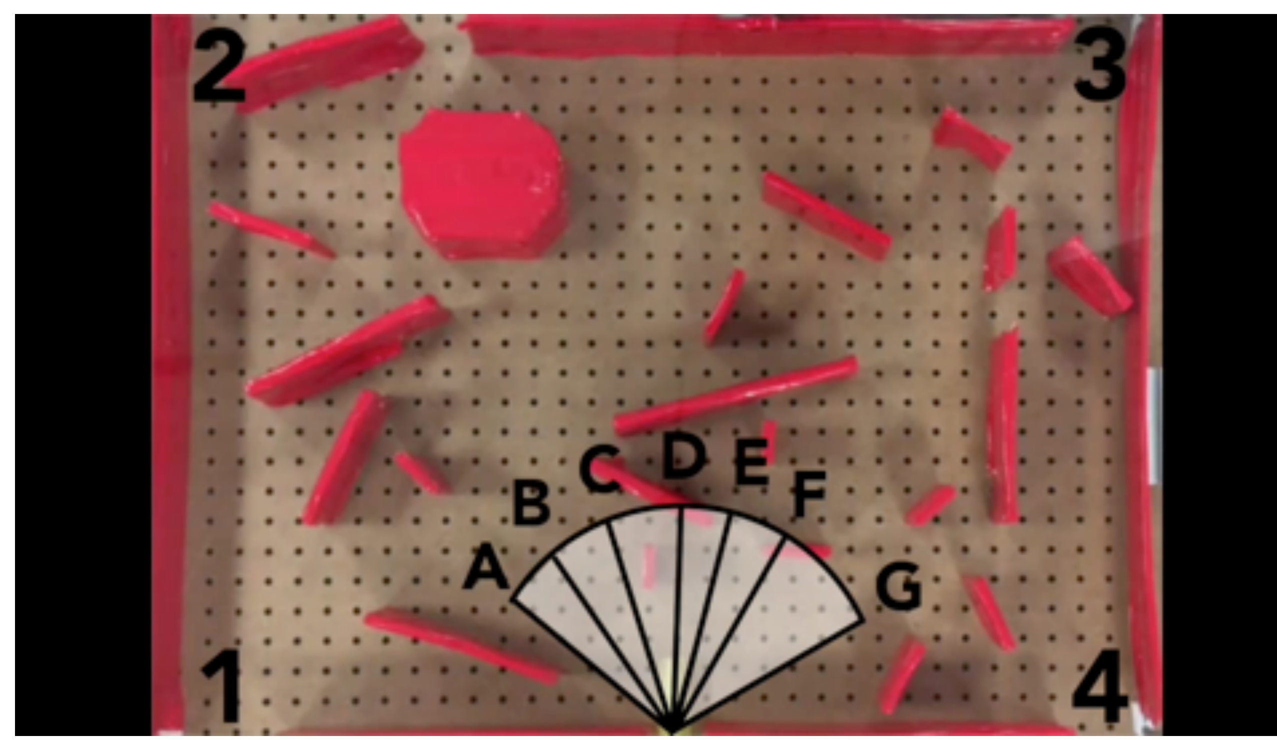
Greer et al. 2019

Applications include scenarios that challenge our ability to safely access and create useful structures in locations remote in distance or scale



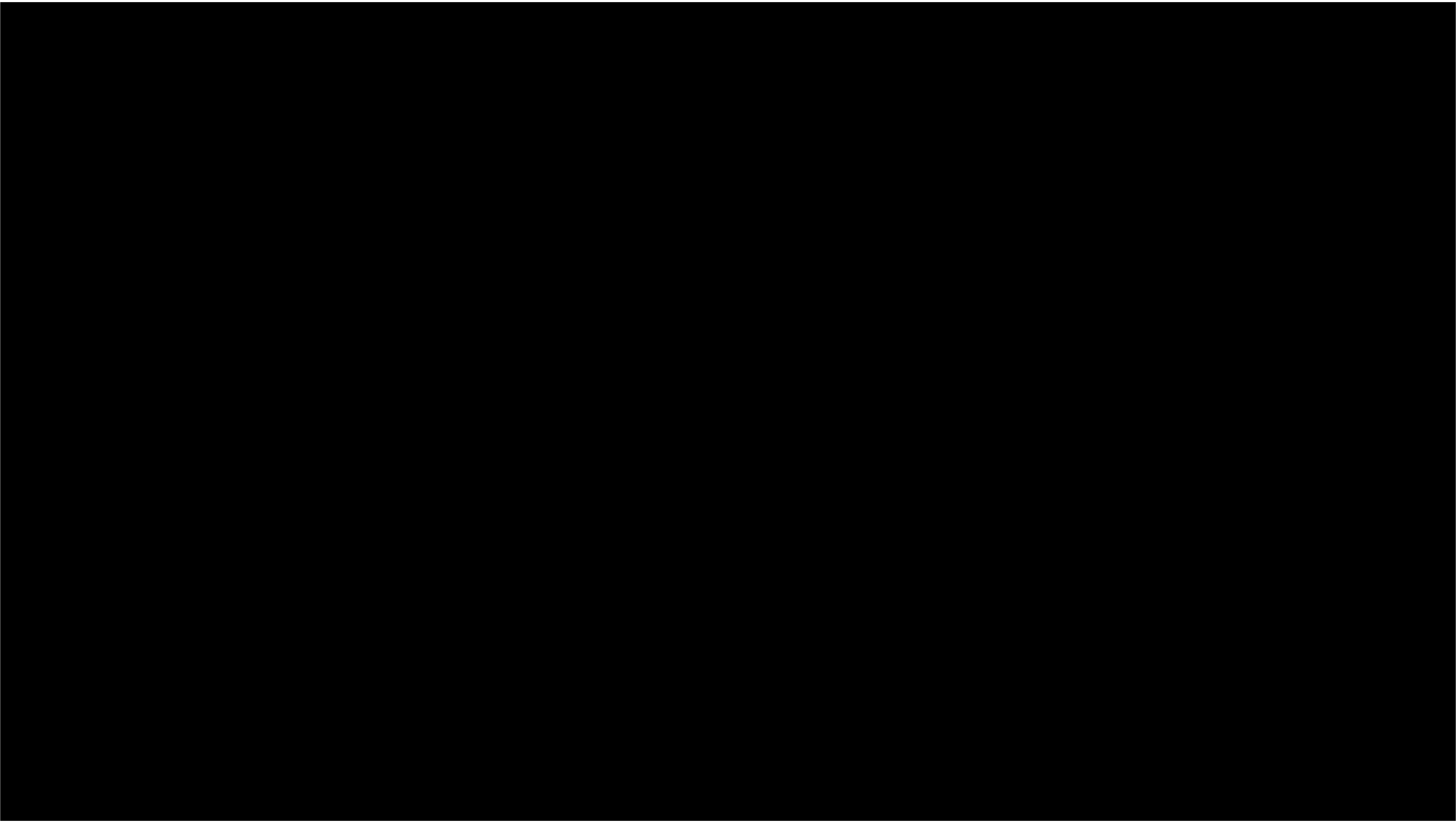






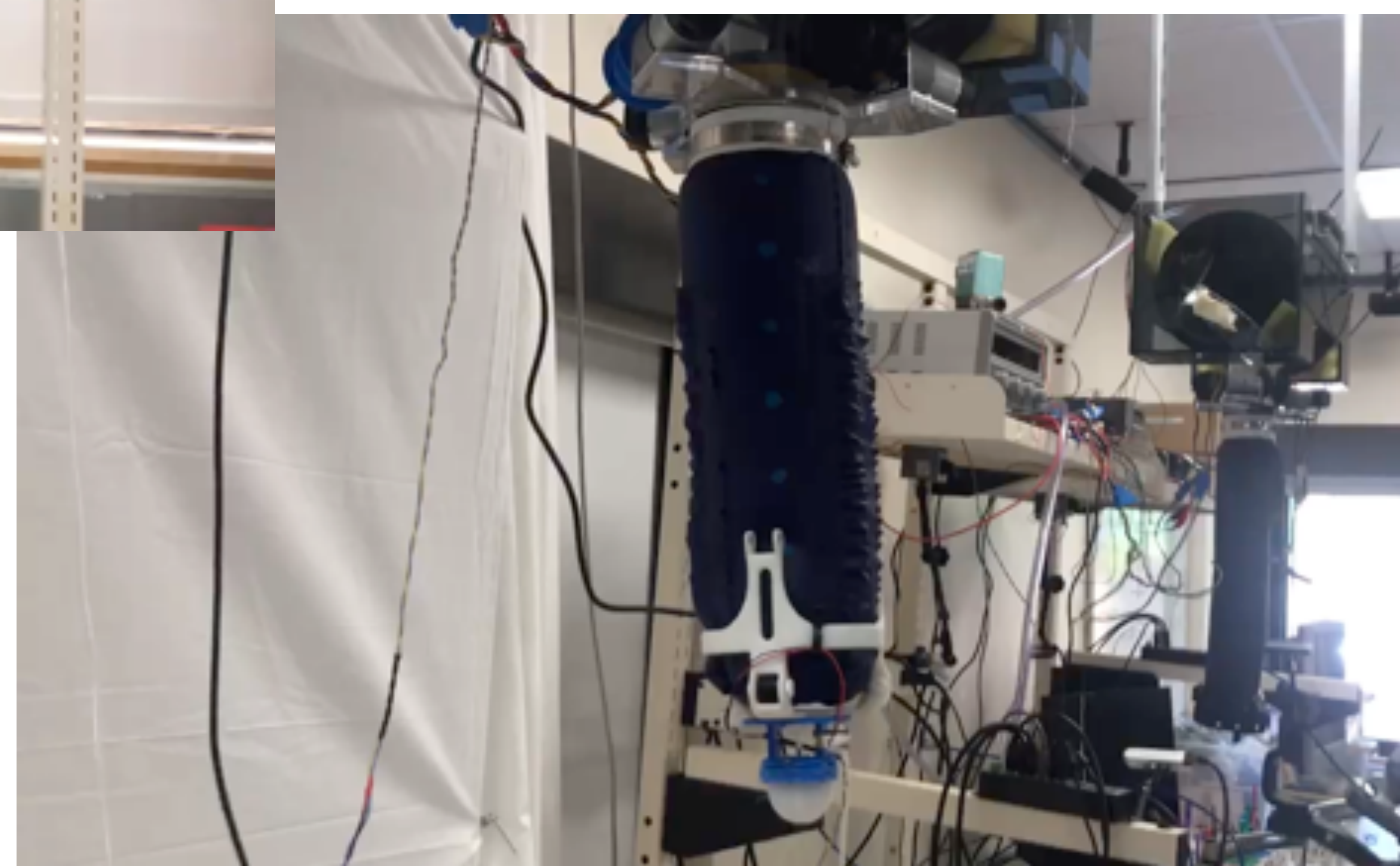
Hawkes et al. Science Robotics 2017, Greer et al. ICRA 2018, IJRR 2020

Archeological Exploration



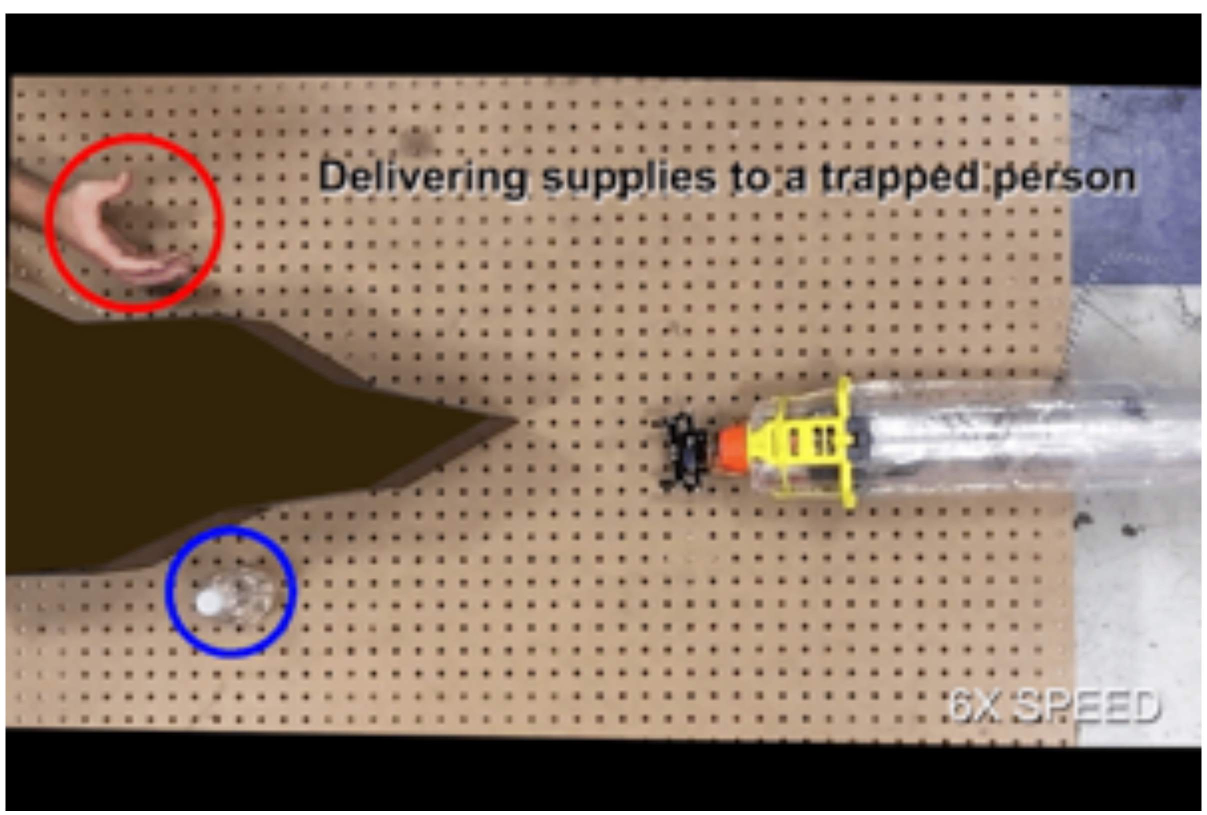
Coad et al. RAM 2019

Toward Manipulation



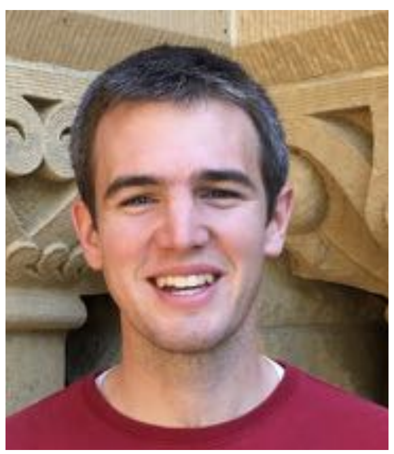
Luo et al. in prep

Toward Manipulation



Do et al. ICRA 2020, Jeong et al. under review, Stroppa et al. ICRA 2020, Luo et al. in prep

Shape-changing isoperimetric truss robots

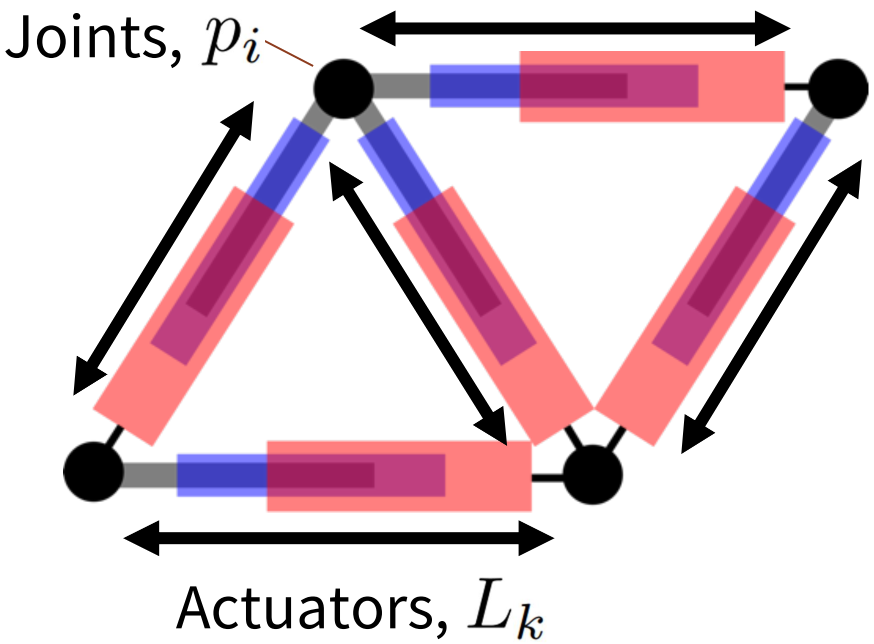


Nathan Usevitch
(Facebook)

Zach Hammond
(Stanford)

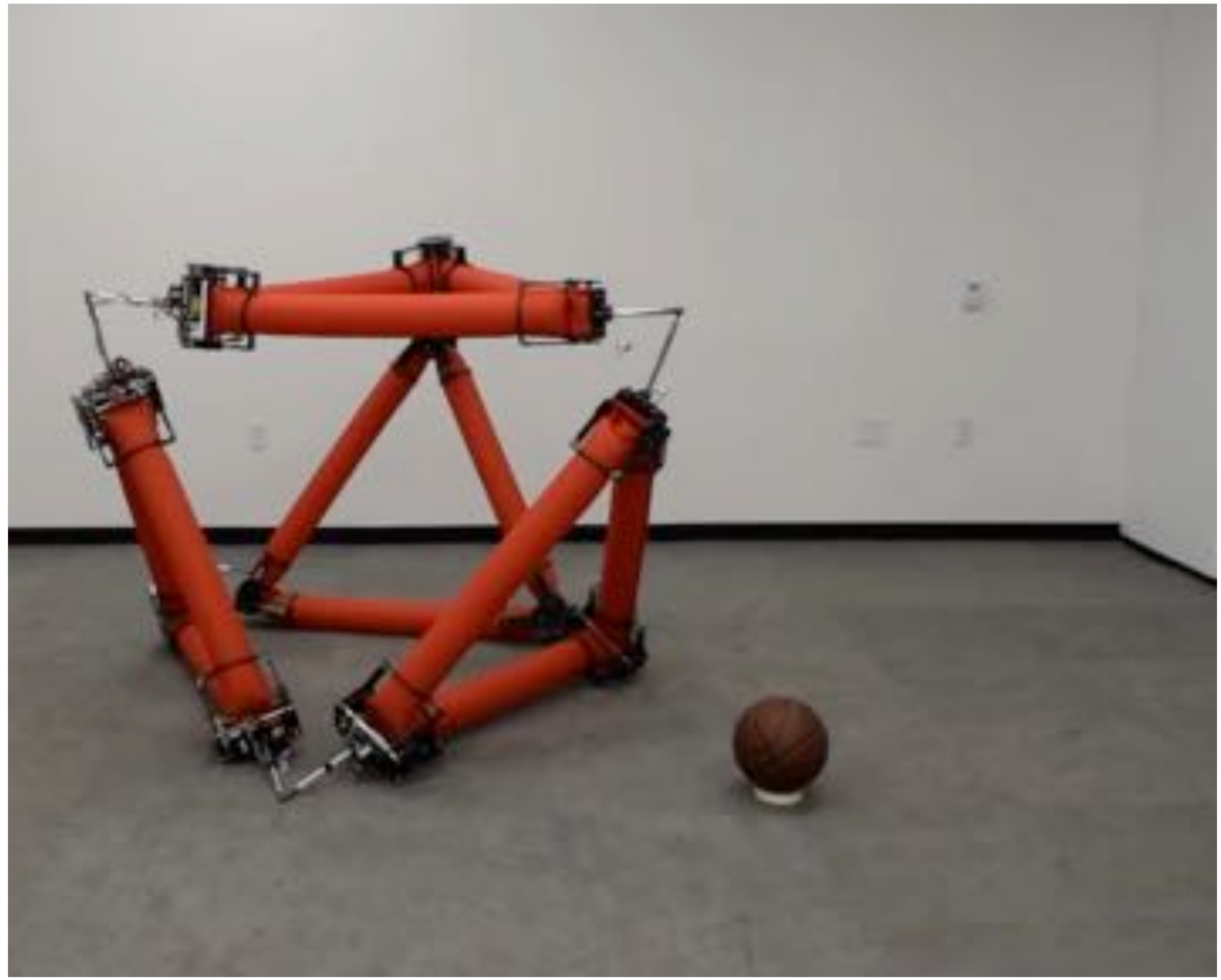
Supported by: National Science Foundation
(With Sean Follmer, Elliot Hawkes, and Mac Schwager)

A “Soft” Truss Robot



NASA Ants 2010

Hamlin et al., 1997
Lee et al., 2001
NASA Superball
Zagal et al., 2012
Spinos et al., 2017
Jeong et al., 2018
Pieber et al., 2018



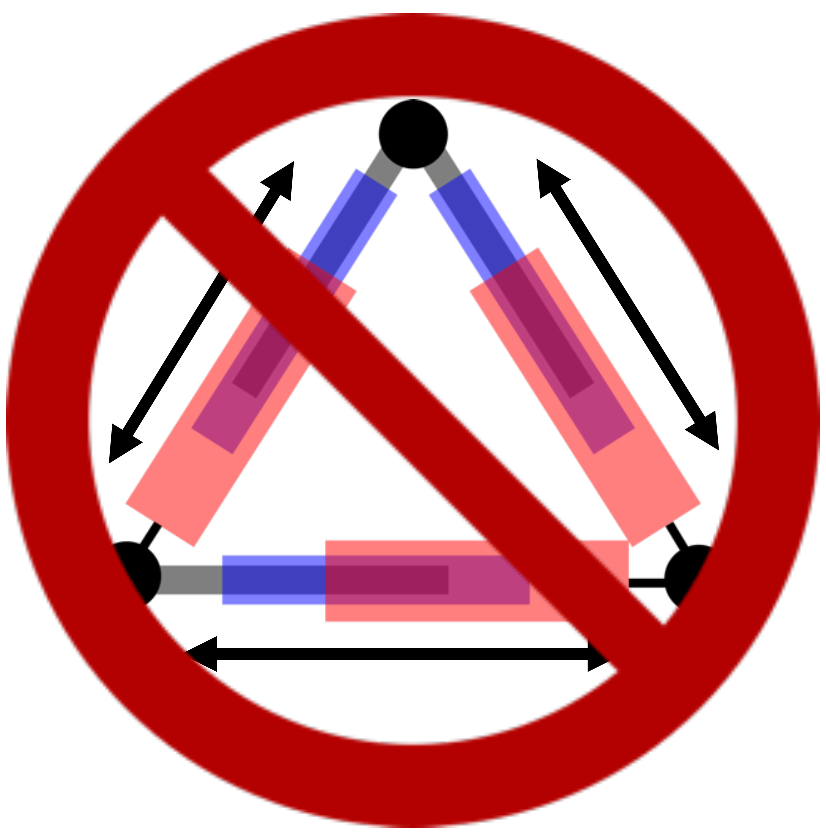
Usevitch, Hammond et al. Science Robotics 2020

Removing the Tether

Usevitch 2018

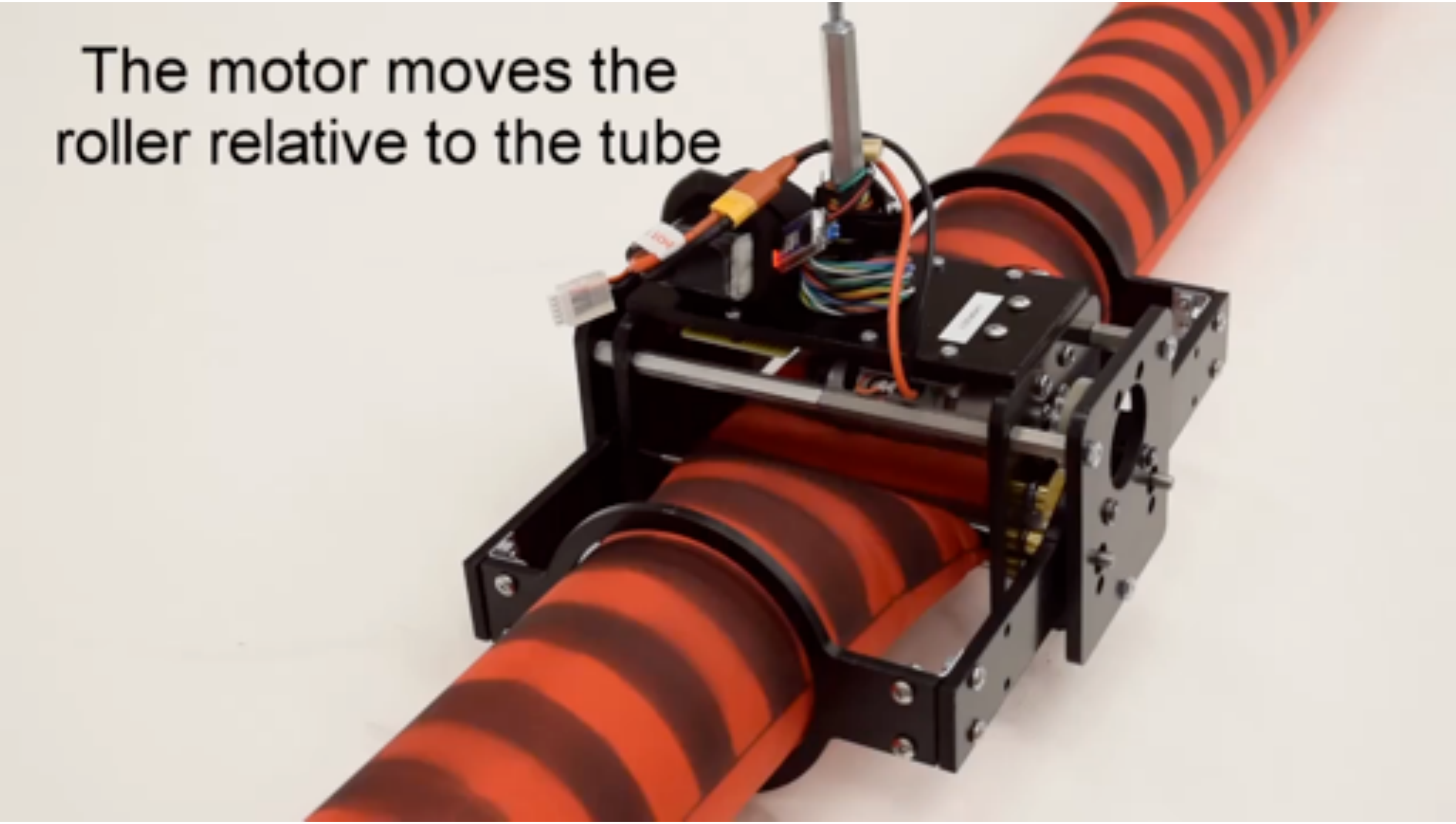

Shepherd 2011

truss formed from a single, continuous member



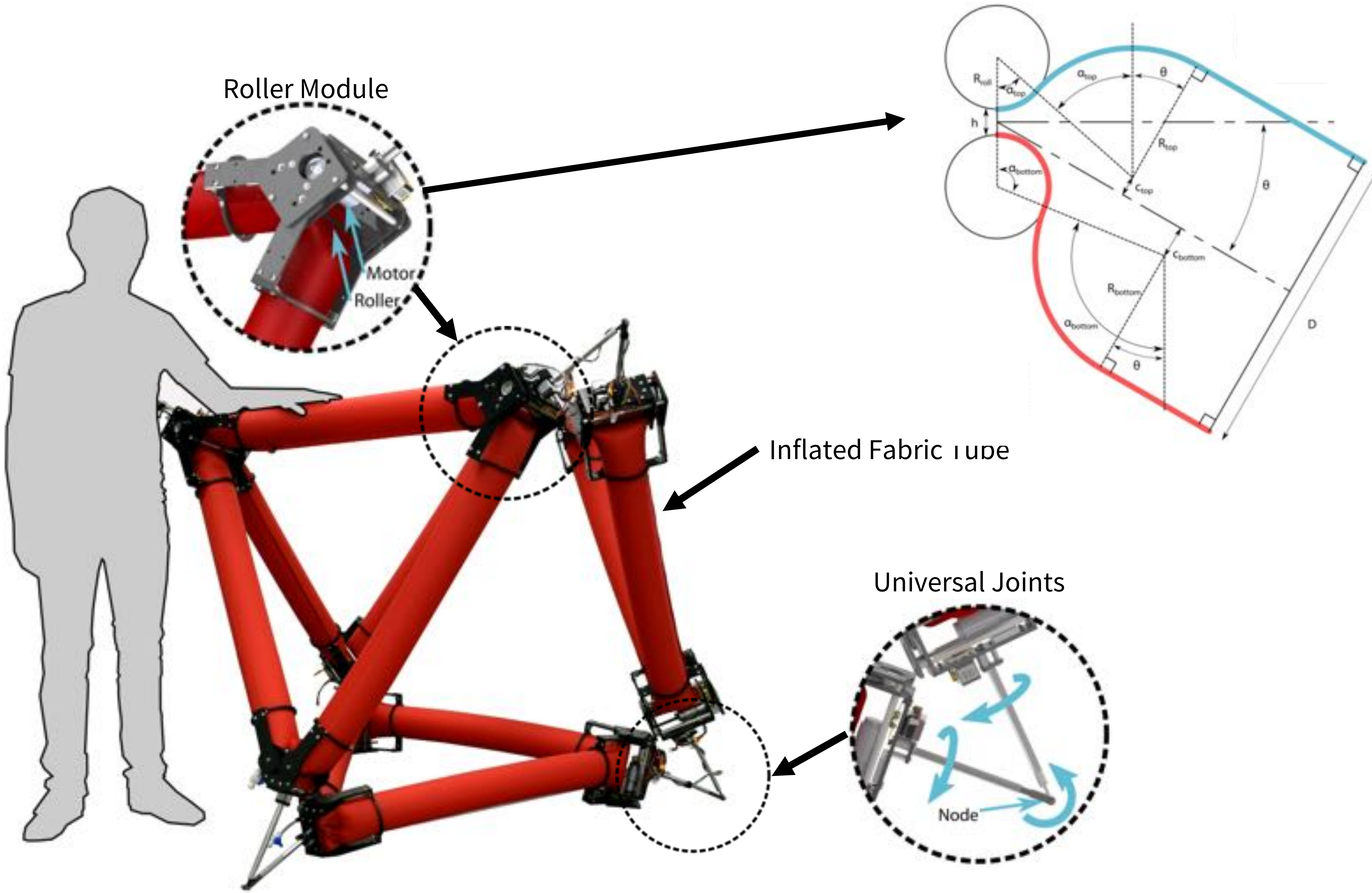
Usevitch, Hammond et al. Science Robotics 2020

Move the joint relative to the structure



Usevitch, Hammond et al. Science Robotics 2020

An Isoperimetric robot



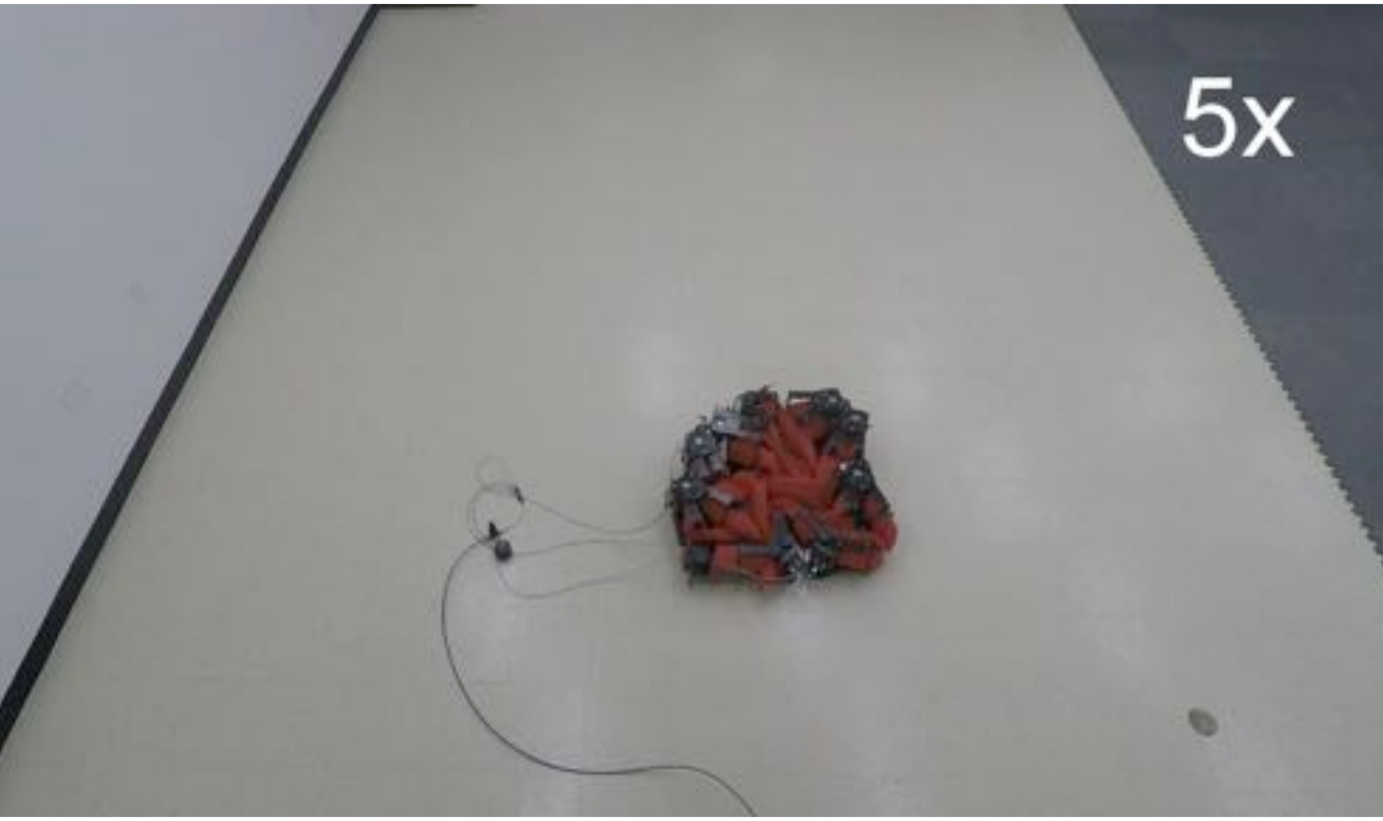
Usevitch, Hammond et al. Science Robotics 2020

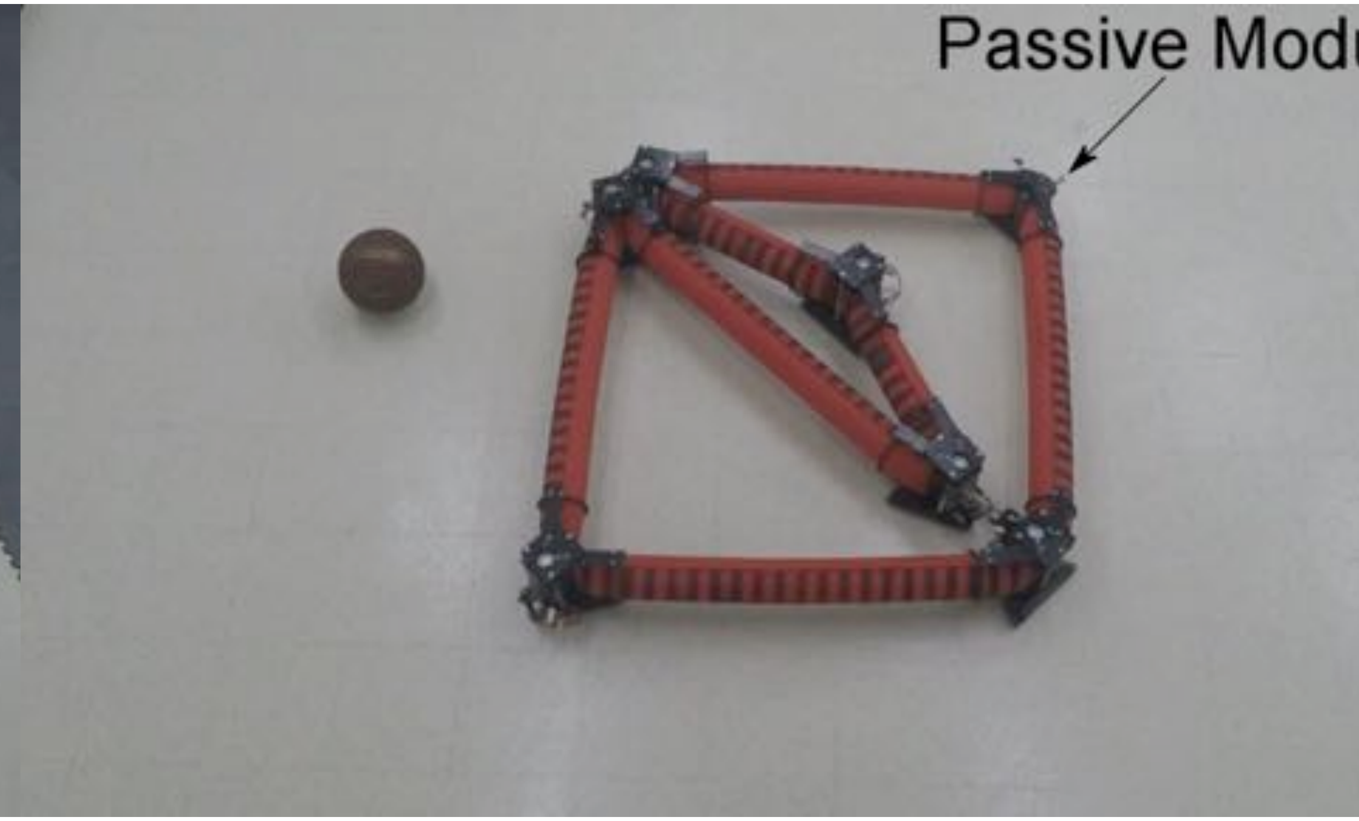
Locomotion

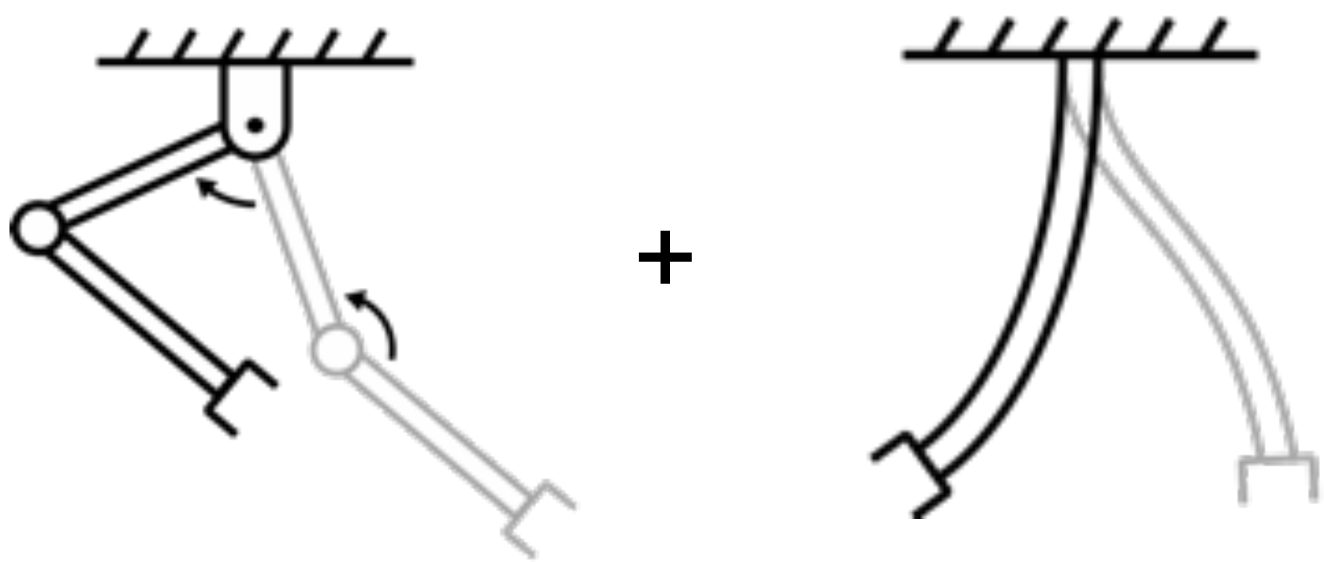
Compliance

Manipulation

Modularity







Towards the best of both worlds

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Soft, steerable, patient-specific medical robots

Robots that grow by tip eversion

Shape-changing isoperimetric truss robots


Tania Morimoto
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Ming Luo
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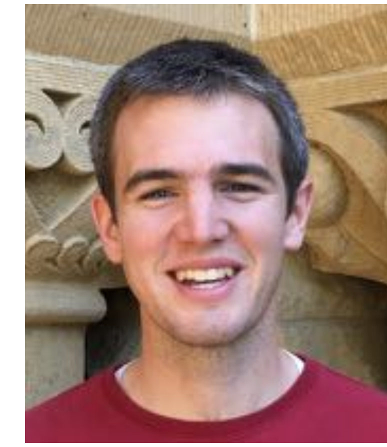
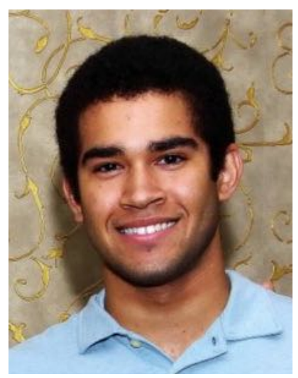
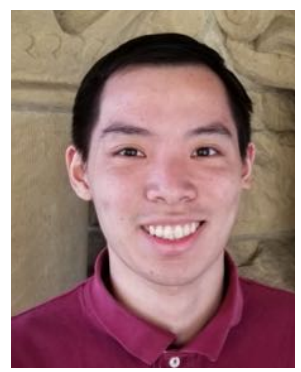

Nathan Usevitch
(Facebook)

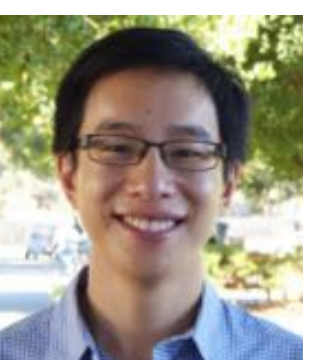

Fabio Stroppa


Margaret Coad


Nathaniel
Agharese


Brian Do


Zach Hammond
(advised by Sean
Follmer)


Jonathan Fan
(Stanford)


Sean Follmer
(Stanford)


Mac Schwager
(Stanford)


Jee-Hwan Ryu
(KAIST)

CHARMers