Haptics: Science and Applications

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Stanford University

Guest lecture for EE 267

hearing

sight

smell

taste

touch

which sense is most valuable to you?

which would you relinquish last?

Katherine Kuchenbecker

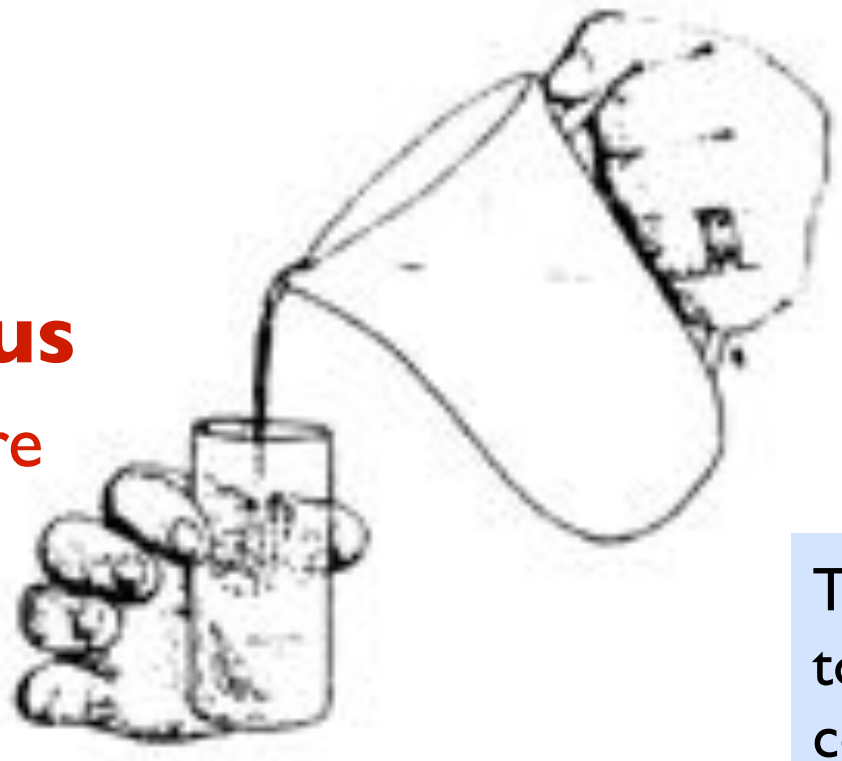
hap·tic ('hap-tik)

adj. Of or relating to the sense of touch.

[Greek *haptikos*, from *haptesthai*, to grasp, touch. (1890)]

Cutaneous

Temperature
Texture
Slip
Vibration
Force



Johansson and Westling

Kinesthesia

Location/configuration
Motion
Force
Compliance

The haptic senses work together with the motor control system to:

- Coordinate movement
- Enable perception

J. Edward Colgate

what would life be like without touch?

Cutaneous

https://www.youtube.com/watch?v=0LfJ3M3Kn80

Kinesthesia

http://www.youtube.com/watch?v=FKxyJfE831Q

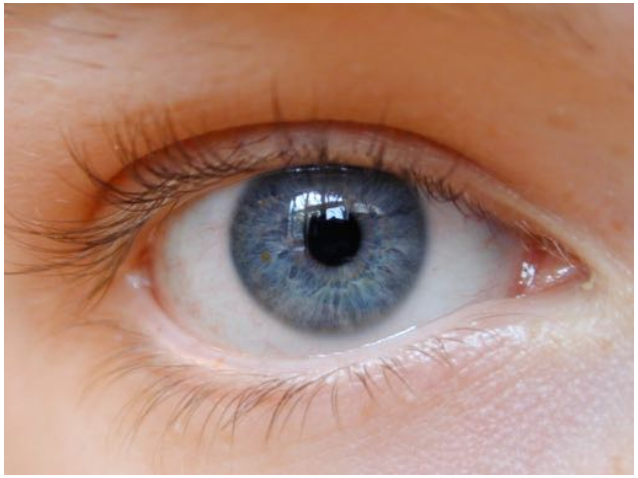
why do we have brains?

sea
squirt

Daniel Wolpert

sight

centralized
broad
passive
cognitive



touch

distributed
narrow
active
physical

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how does your computer/ smartphone/iPad see you?

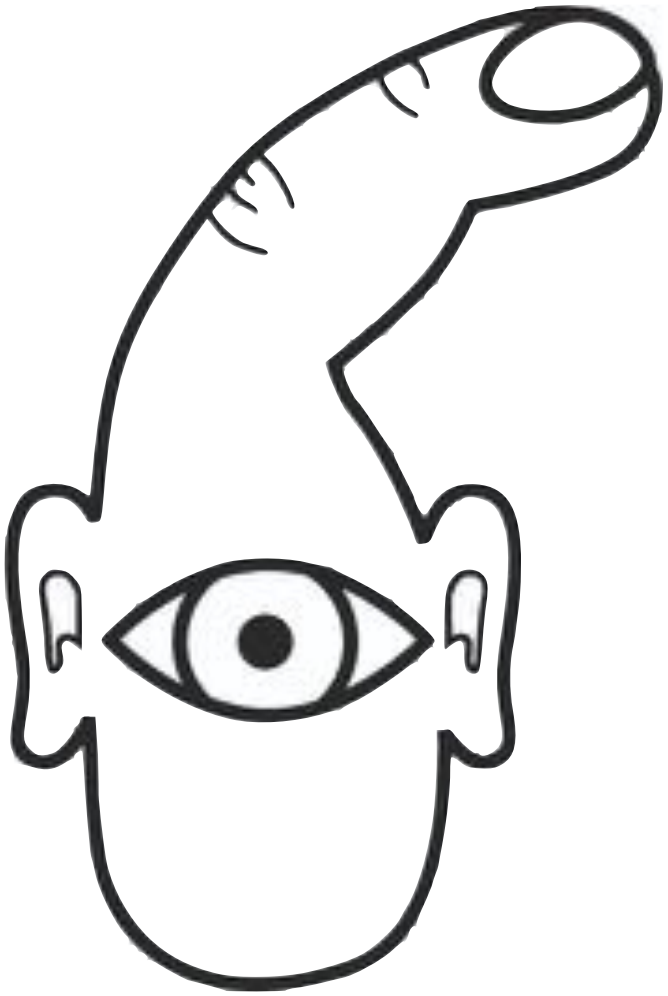

illustration by Tom Igoe

tactual stereognosis

- Tactual = tactile = via the sense of touch
- Stereognosis = the mental perception of three-dimensionality by the senses, usually in reference to perceiving the form of solid objects by touch
- One study (Klatzky et al., 1985) showed that subjects could identify 100 common objects almost perfectly, taking about 2 seconds per object.
- People are *very good* at tactual stereognosis.

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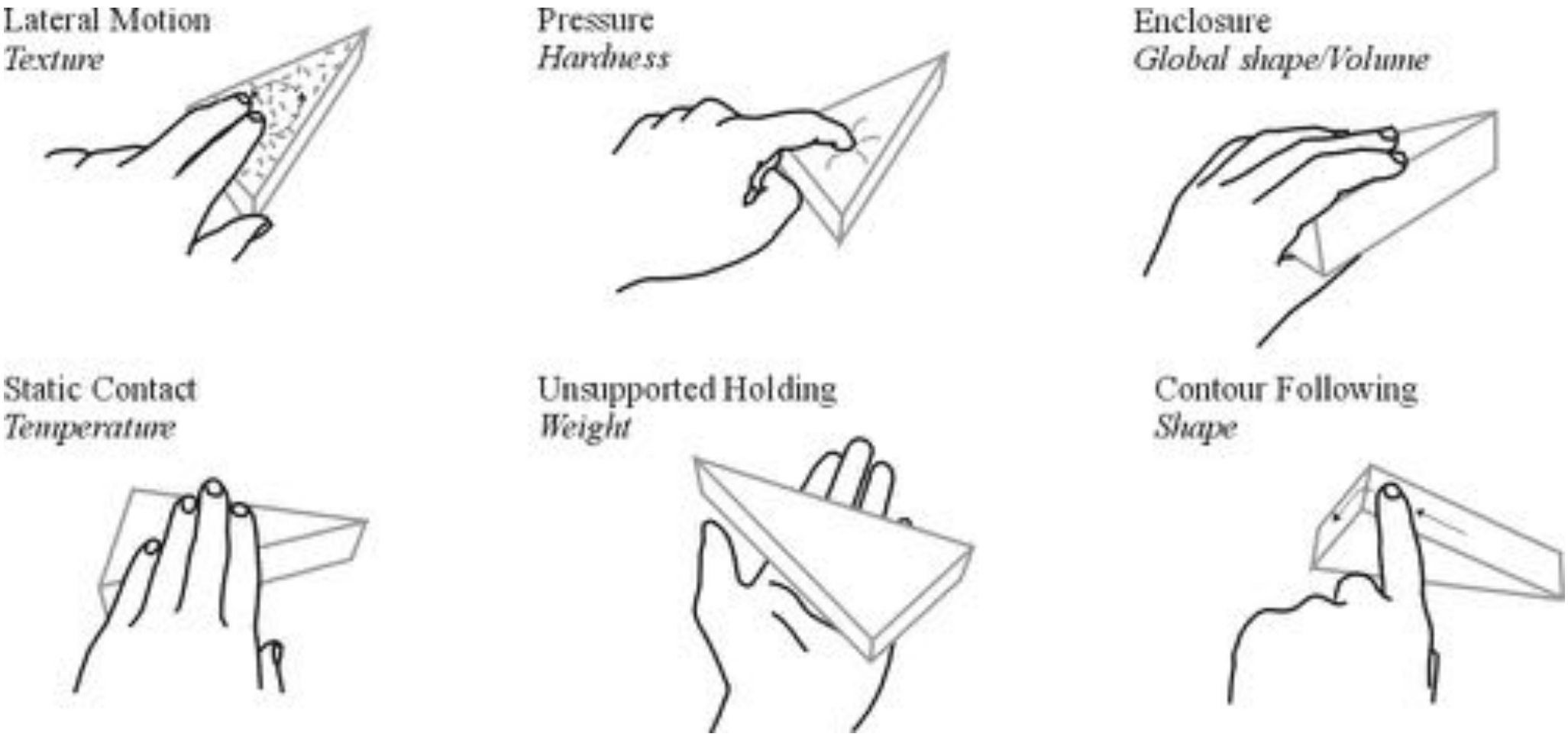
haptic exploratory procedures



Adapted from R.L. Klatzky, et al., "Procedures for haptic object exploration vs. manipulation," Vision and action: The control of grasping, ed. M. Goodale, New Jersey: Ablex, 1990, pp. 110-127.

Tactile Devices

Stimulate skin to create contact sensations

Hybrid Devices

Attempt to combine tactile and kinesthetic feedback

Kinesthetic Devices

Apply forces to guide or inhibit body movement

K. Kuchenbecker

existing applications of haptics

entertainment

Nintendo

education

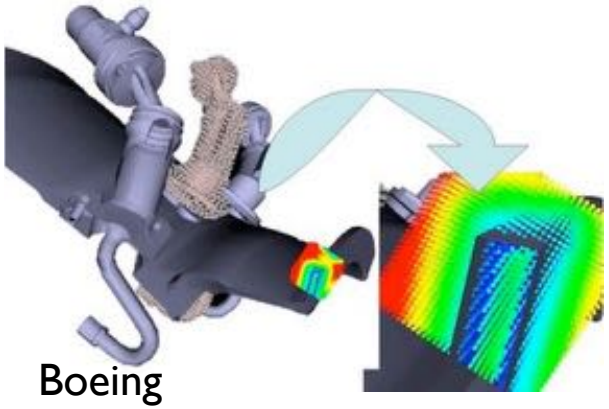
Stanford/JHU

Immersion

human-computer interfaces

BMW

Samsung



Boeing

human haptics: why do we study it?

- for **science**
- to cure diseases and deficits
- as engineers:
  - to make useful and effective haptic simulations
  - to set a limit of how good haptic simulations have to be (efficiency)
  - because haptic devices can be used in psychophysical/ perceptual tests (an application of haptic technology)

types of haptic sensing

tactile

spatial form (SA I)
texture (SA I, PC)
movement (RA)
flutter (RA)
vibration (PC)

stereognosis

(SA I, Proprioceptors)

pain

pricking pain (A δ)
burning pain (C fiber)

muscle force

(Golgi tendon organs)

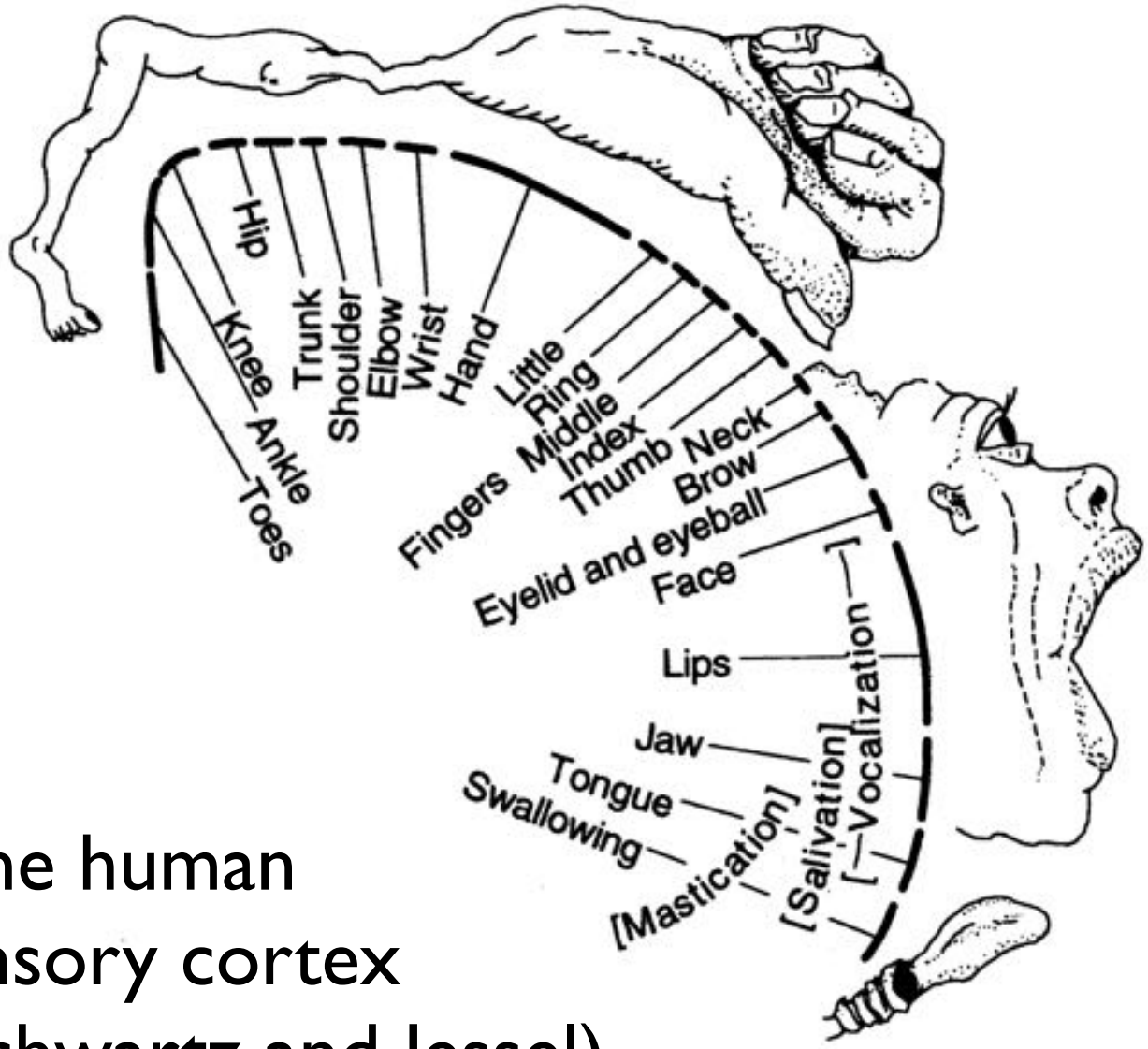
temperature

cold (A δ)
warm (C fiber)

body position/movement

(SA II, joint afferents, muscle spindles)

sensory homunculus



mapping the human somatosensory cortex (Kandel, Schwartz and Jessel)

active vs. passive touch

- Active touch
  - Focus on the object
- Passive touch
  - Focus on the sensation experienced
- Try it
- Is active touch better?
  - *Purposiveness* vs. movement over skin
  - In 3D, yes
- How is this important to haptic device design?

mechanoreception

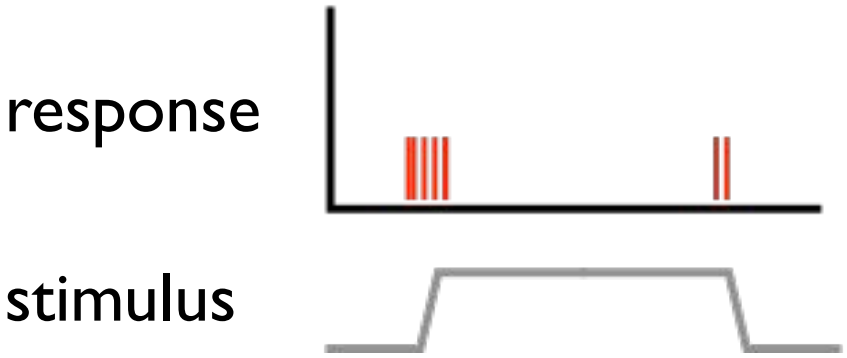
mechanoreceptive afferents

classified by depth:
I: closer to skin surface
II: deeper beneath surface

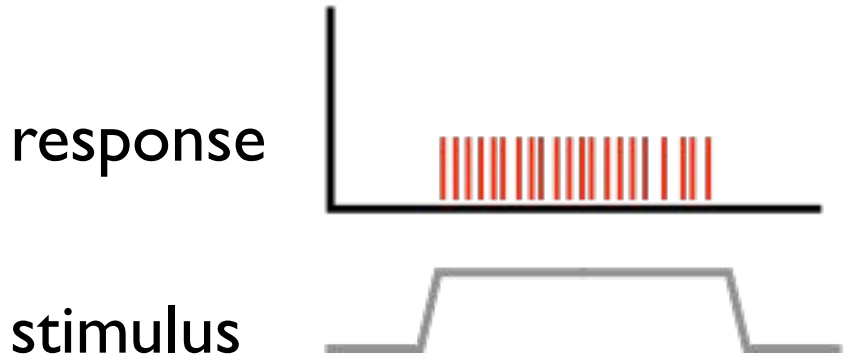
classified by rate of adaptation:
rapidly adapting = phasic
slowly adapting = tonic

classified by sending modality:
e.g., receptor structure

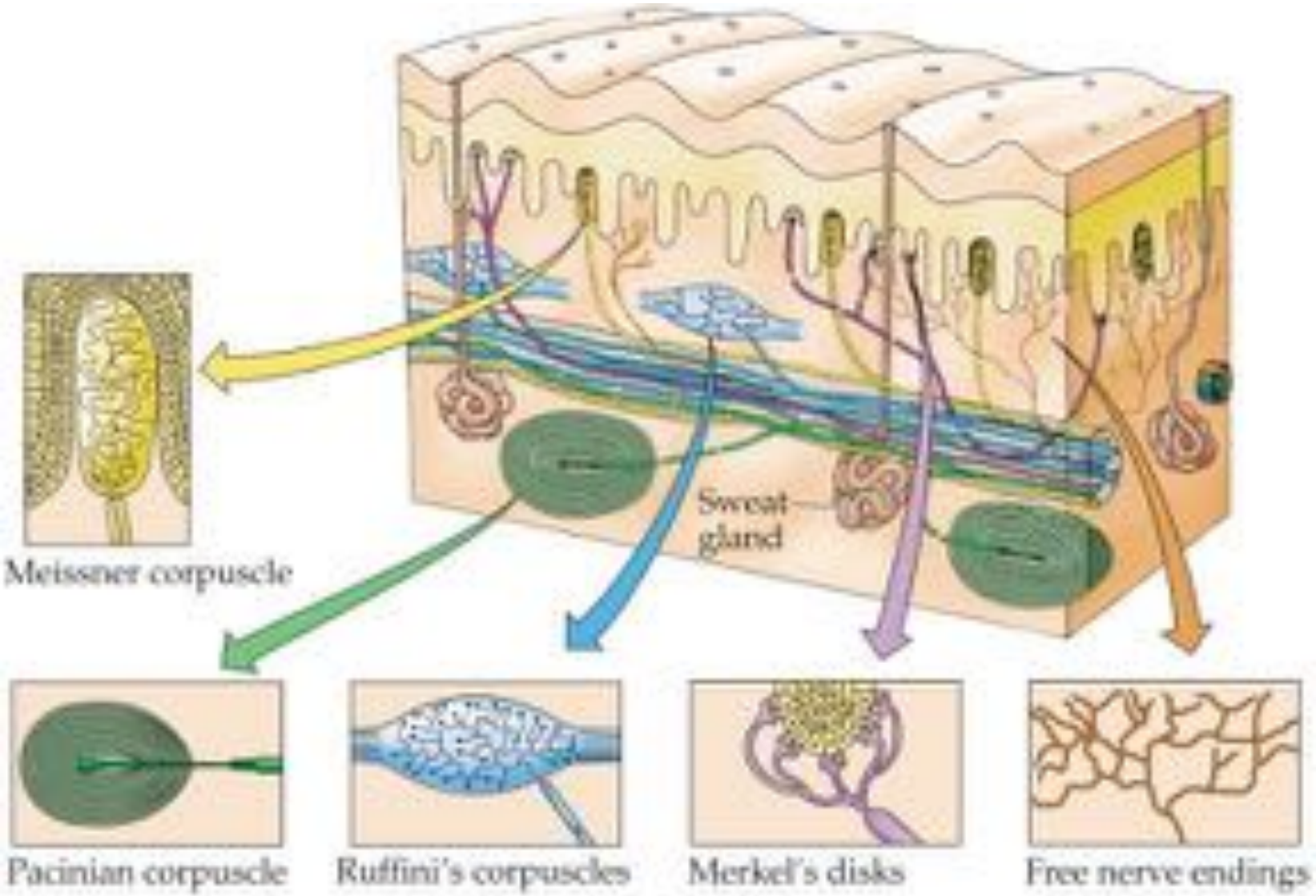
rapidly adapting (RA)



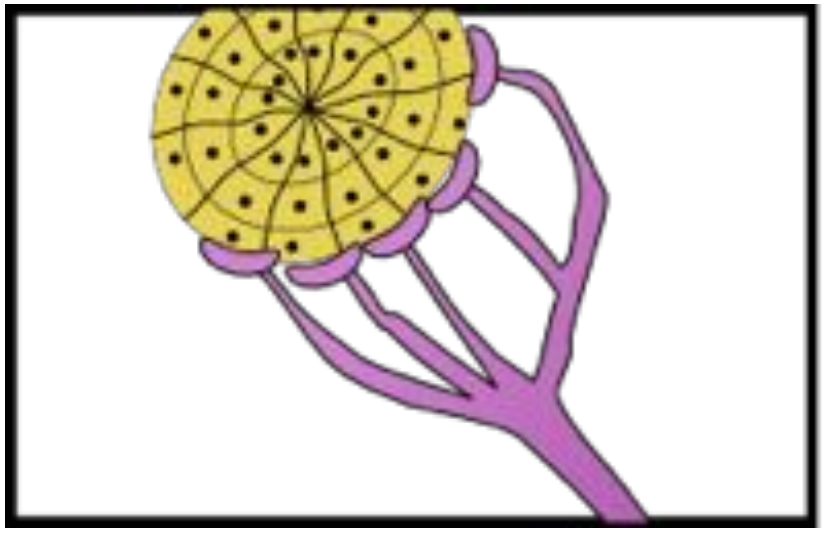
slowly adapting (SA)



cross section of glabrous skin



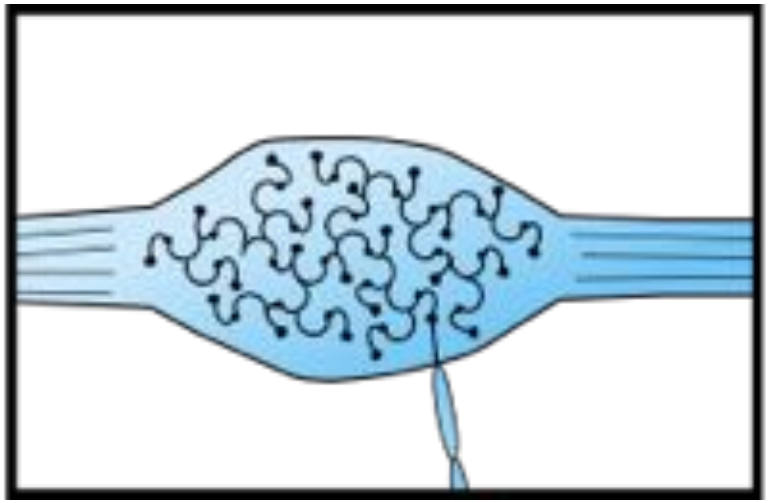
Merkel (SA I)



- form and texture perception
- low-frequency vibrations

Shape: disk
Location: near border between epidermis & dermis
Type: SA I
Best Frequencies: 0.3-3 Hz
Stimulus: pressure

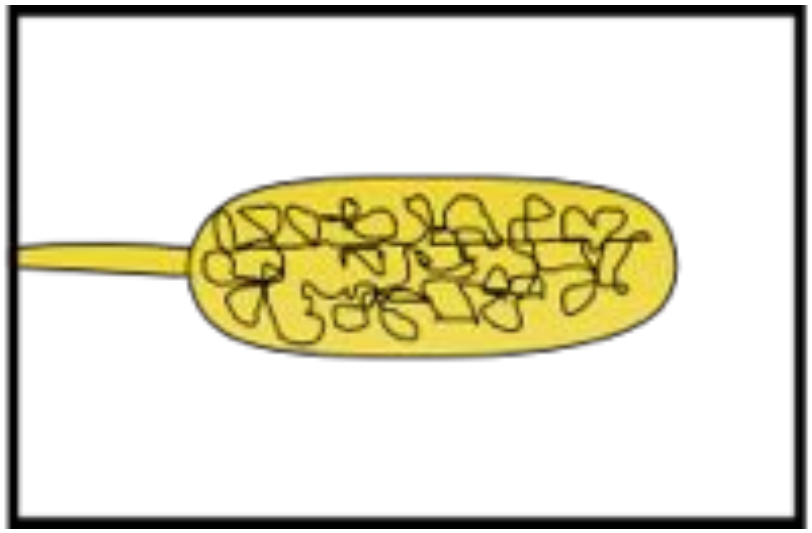
Ruffini (SA II)



- static and dynamic skin deformation
- skin stretch

Shape: many-branched fibers inside a roughly cylindrical capsule
Location: dermis
Type: SA II
Best Frequencies: 15-400 Hz
Stimulus: stretching of skin or movement of joints

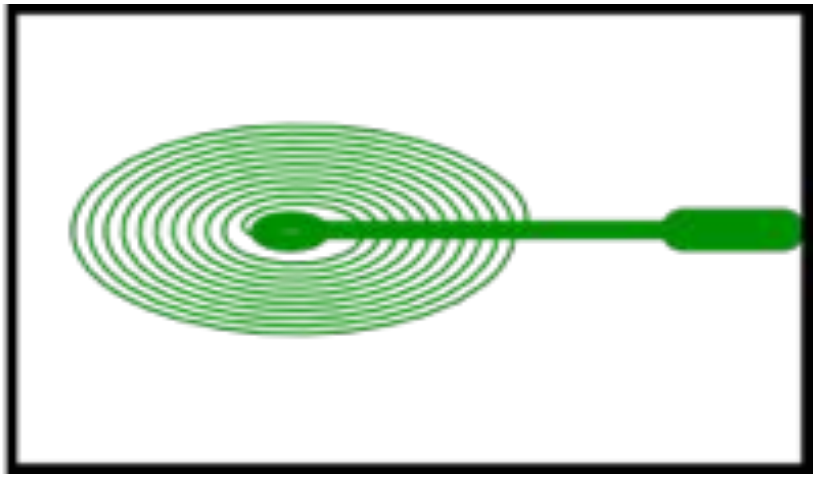
Meissner (RA I)



- motion, slip/grip
- dynamic skin deformation

Shape: stack of flattened cells, with a nerve fiber winding its way through
Location: in dermis just below epidermis
Type: RA I
Best Frequencies: 3-40 Hz
Stimulus: taps on skin

Pacinian Corpuscle (PC / RA II)



- high frequency vibration
- gross pressure changes

Shape: layered capsule surrounding nerve fiber
Location: deep in skin
Type: PC
Best Frequencies: 10 to >500 Hz
Stimulus: rapid vibration

cutaneous mechanoreceptors

	Receptor	Diam.	Density (Fibers/cm^2)	Response	Percep. Function
SA I	Merkel	2mm	100	curvature	form & texture
RA	Meissner	5 mm	150	motion	motion & grip control
SA II	Ruffini	8mm	20	stretch	hand shape, lateral force
PC	Pacinian	Hand	20	vibration	tools & probes

kinesthesia

kinesthetic sensing

perception of limb movement & position, **force**

- muscle receptors (muscle spindles and Golgi tendon organs)
- joint receptors (in capsules and ligaments of joints)
- skin receptors (slowly adapting cutaneous mechanoreceptors that measure skin stretch): Ruffini endings, Merkel Cells in hairy skin

force sensing

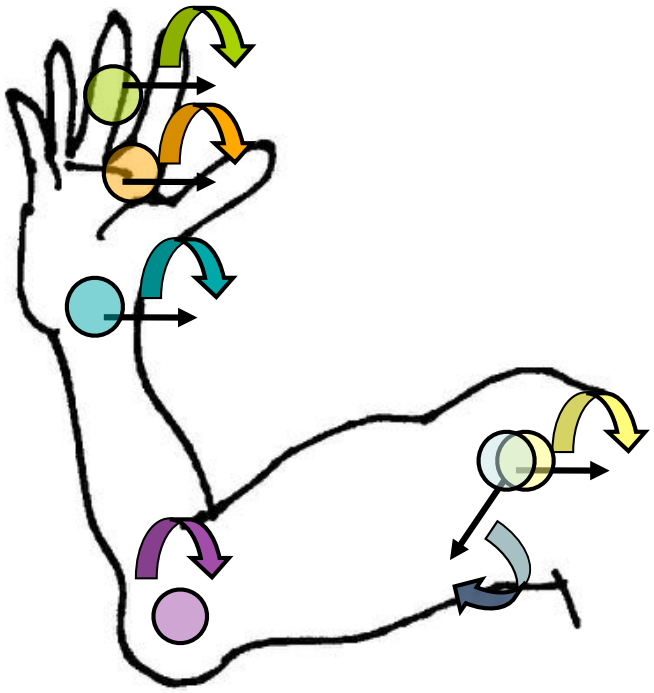
- Resolution 0.06 N
- Grasping force: 400 N!
- Which of the following objects weighs about one Newton?

automobile, Isaac Newton, bowling ball, baseball, a dime

proprioception

- derived from Latin, *proprius*, meaning "belonging to one's own self"
- in general, it provides a sense of static position and movement of the limbs and body in relation to one other and the world
- in much of the literature, proprioception is defined as the perception of positions and movements of the body segments in relation to each other (without aid of vision, touch, or the organs of equilibrium). This is in contrast to **exteroception**.

Just Noticeable Differences at Joints



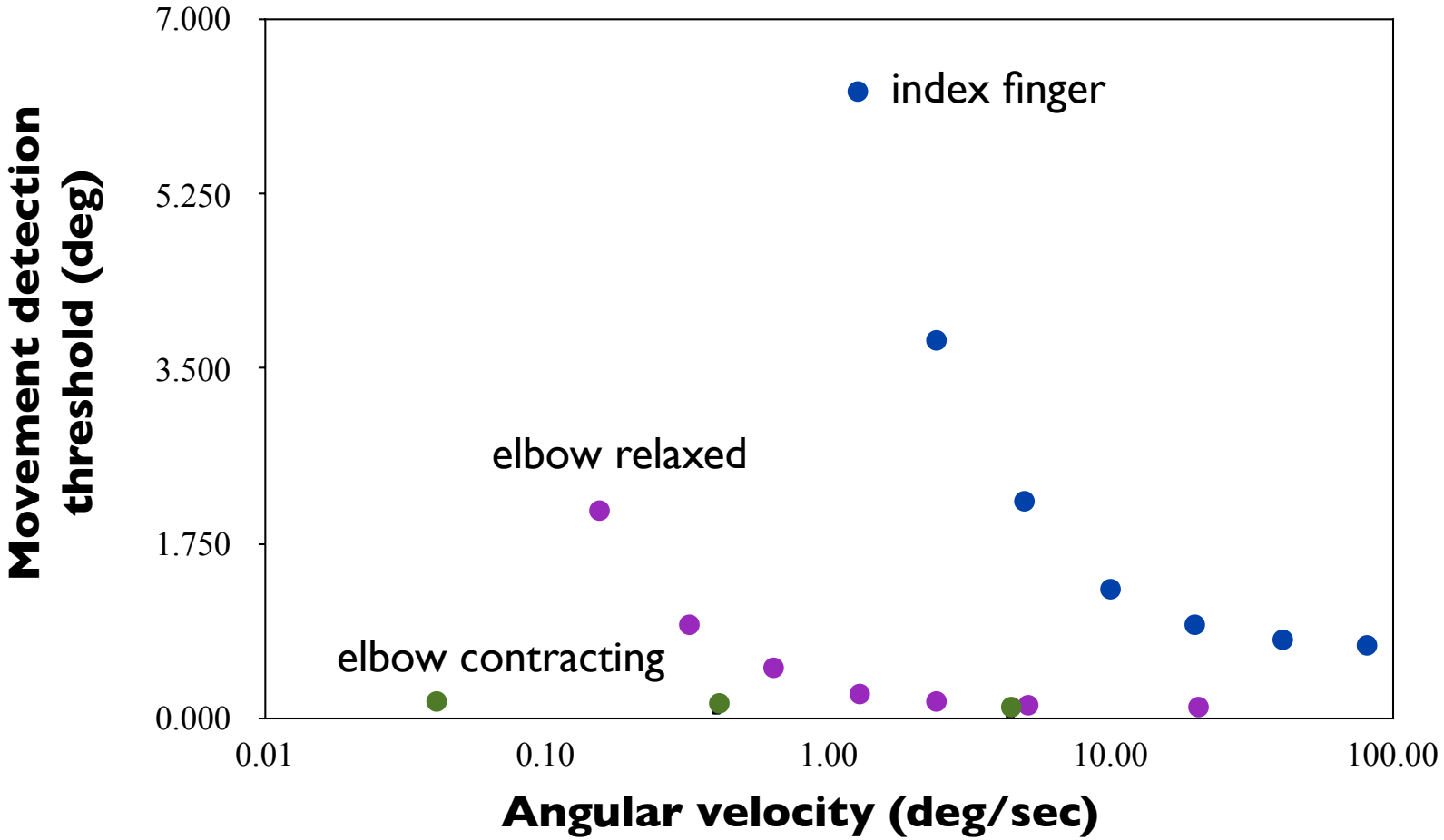
	Proximal-InterPhalangeal (PIP) Joint	~2.5°/*6.8°
	MetaCarpalPhalangeal (MCP) Joint	~2.5°/*4.4°
	Wrist	2.0°
	Elbow	2.0°
	Shoulder (front)	0.8°
	Shoulder (side)	0.8°

H. Z. Tan, M. A. Srinivasan, B. Eberman, and B. Cheng, "Human factors for the design of force-reflecting haptic interfaces." In Proc. of 3rd Int. Symp. Haptic Interfaces for Virtual Environment and Teleoperator Systems, ASME Dynamic Systems and Control Division, 55(1):353-359, 1994.

L. A. Jones, "Kinesthetic Sensing", unpublished, 2000.

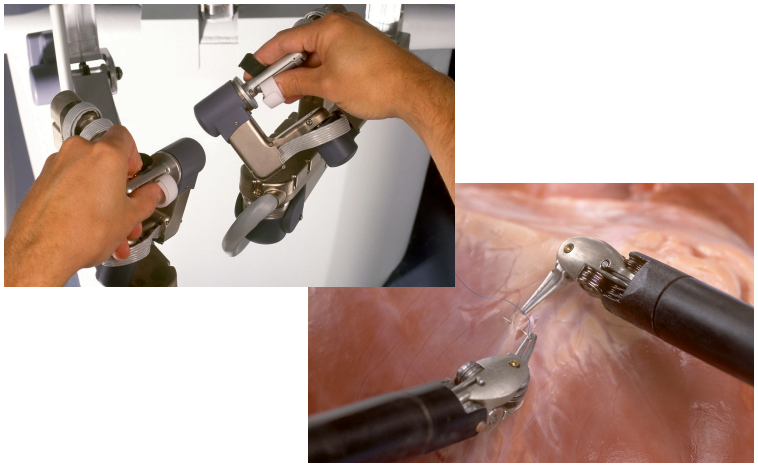
movement and position

threshold can depend on velocity and whether muscle is contracted

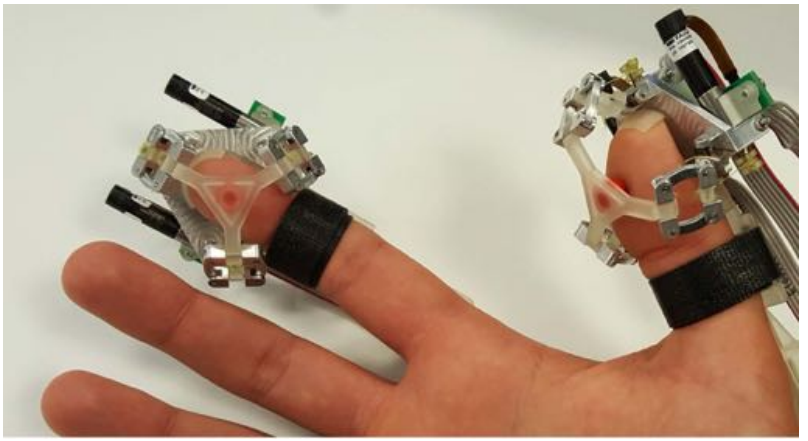


Jones, 2000

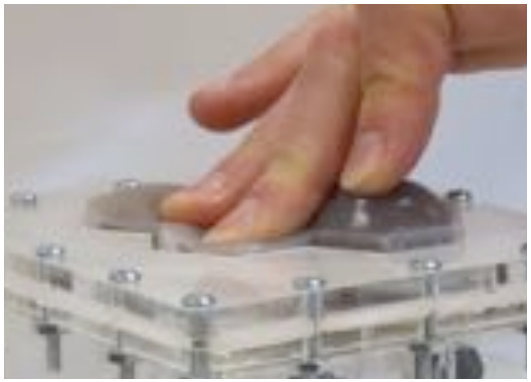
Robot-Assisted Surgery



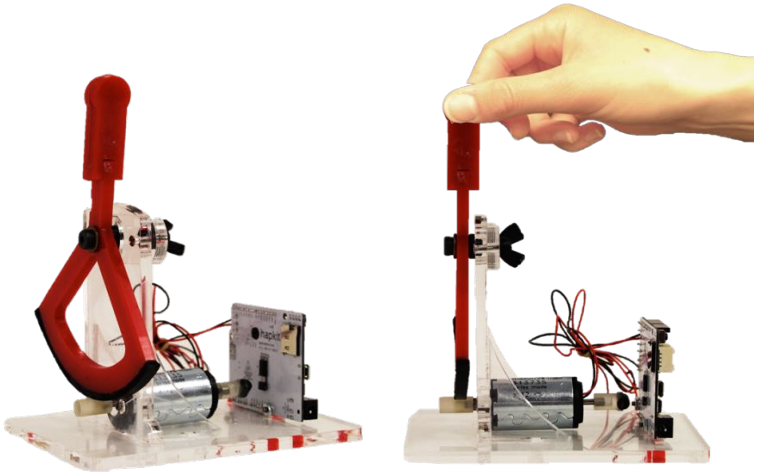
Fingertip Haptics



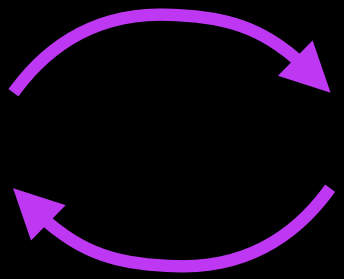
Active Surfaces

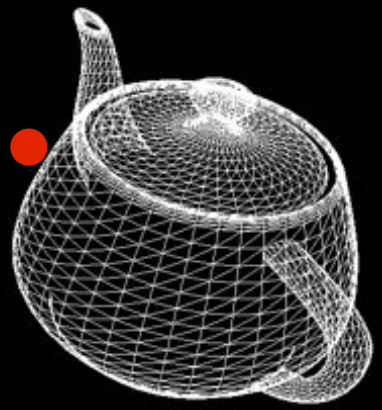


Education



motion and
force signals

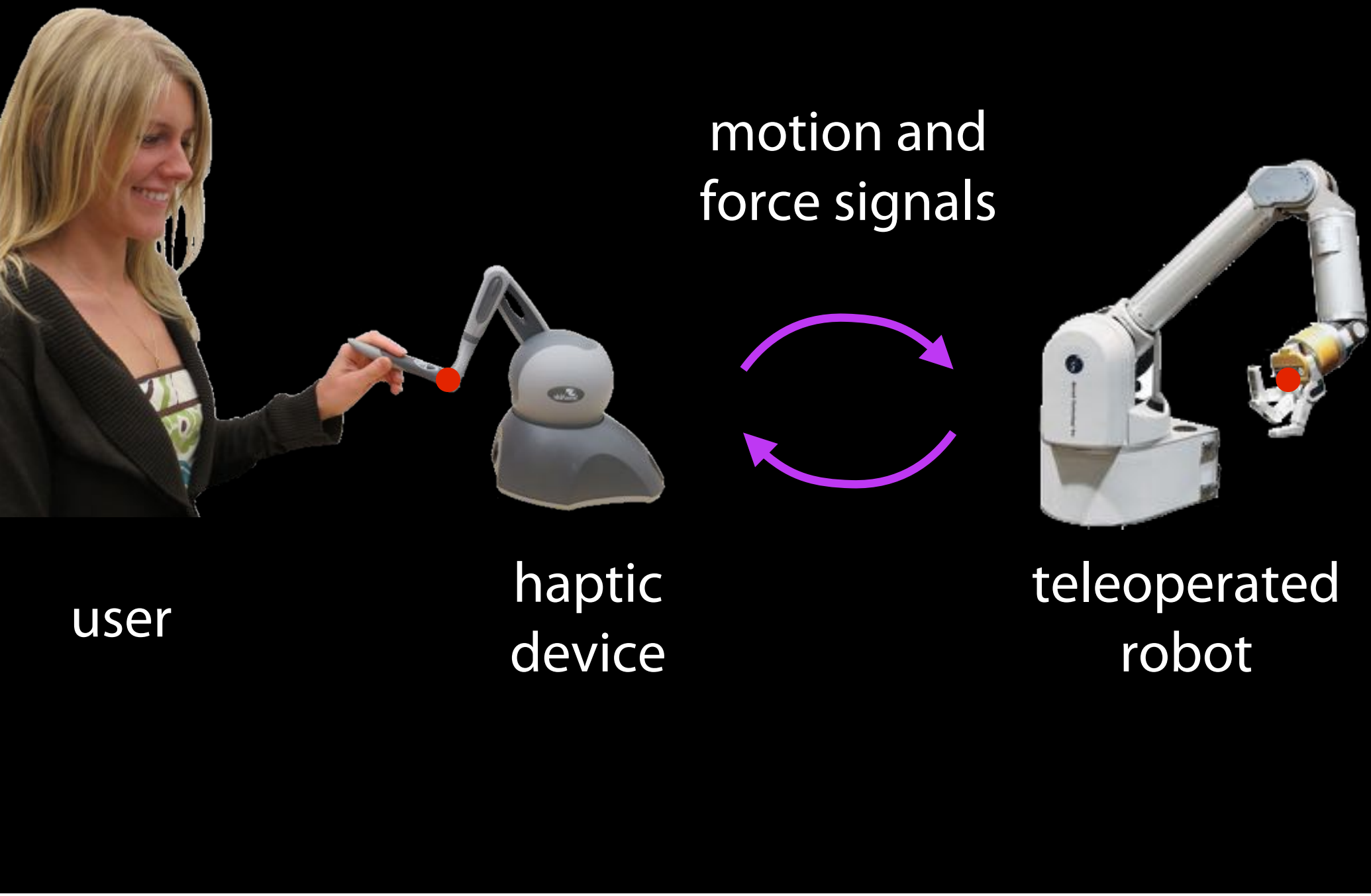


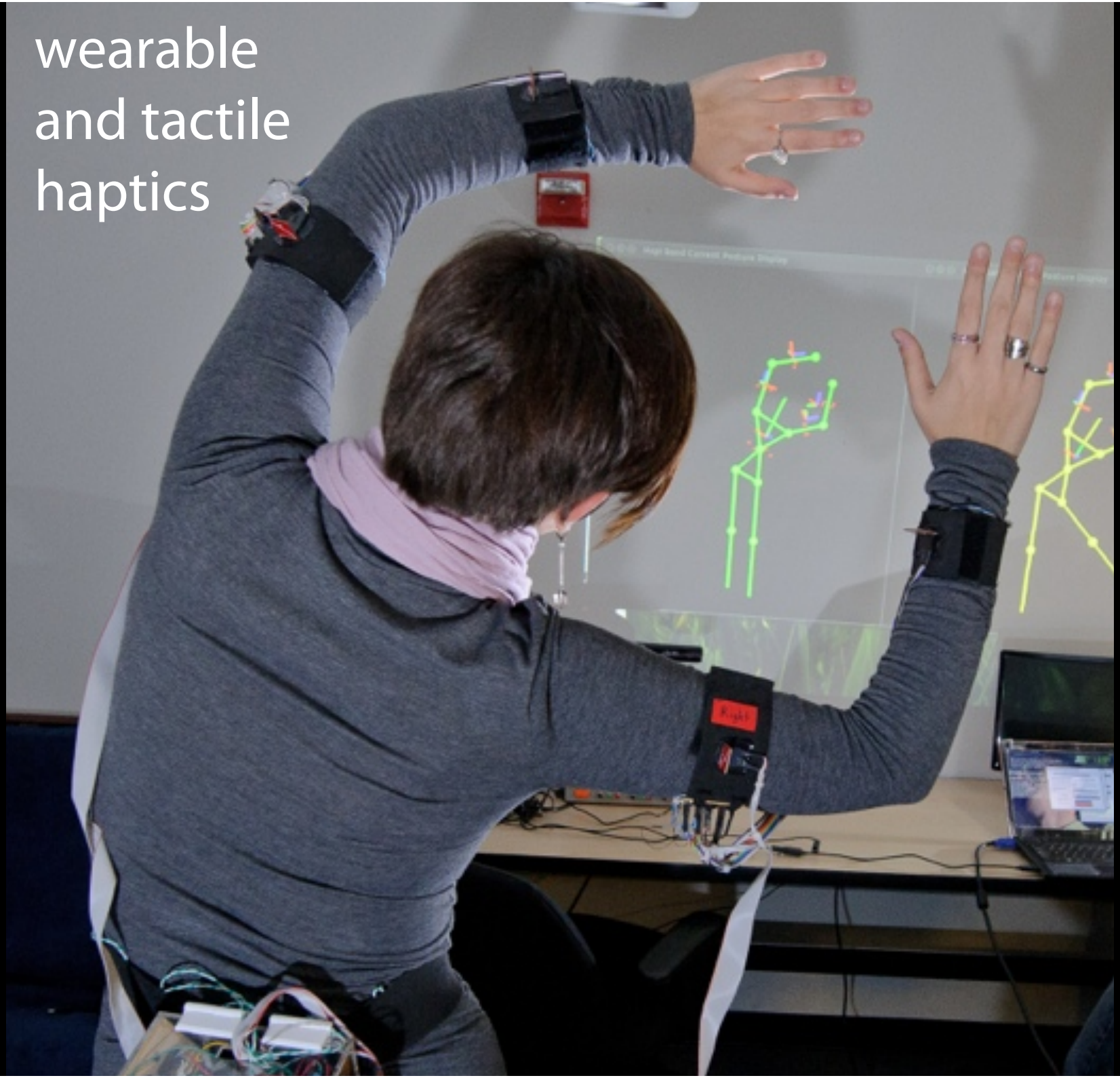


user

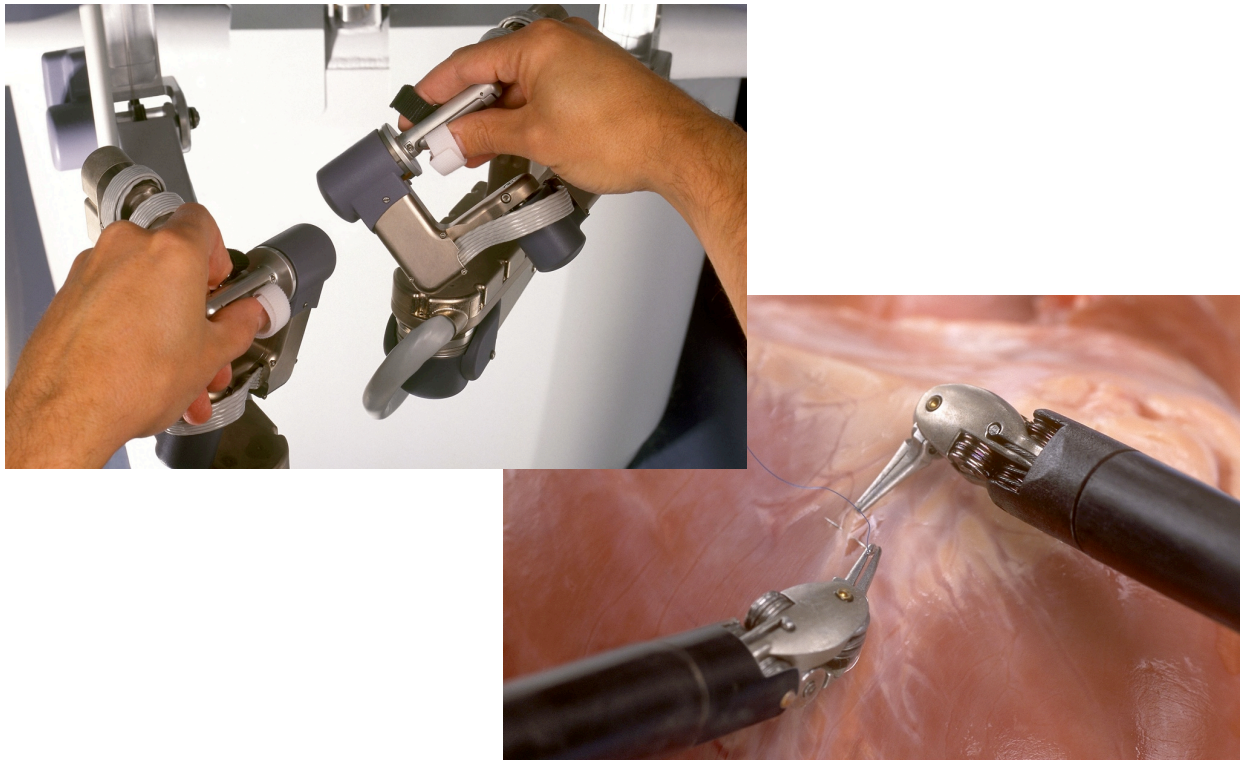
haptic
device

virtual
environment


motion and
force signals
user
haptic
device
teleoperated
robot


wearable
and tactile
haptics

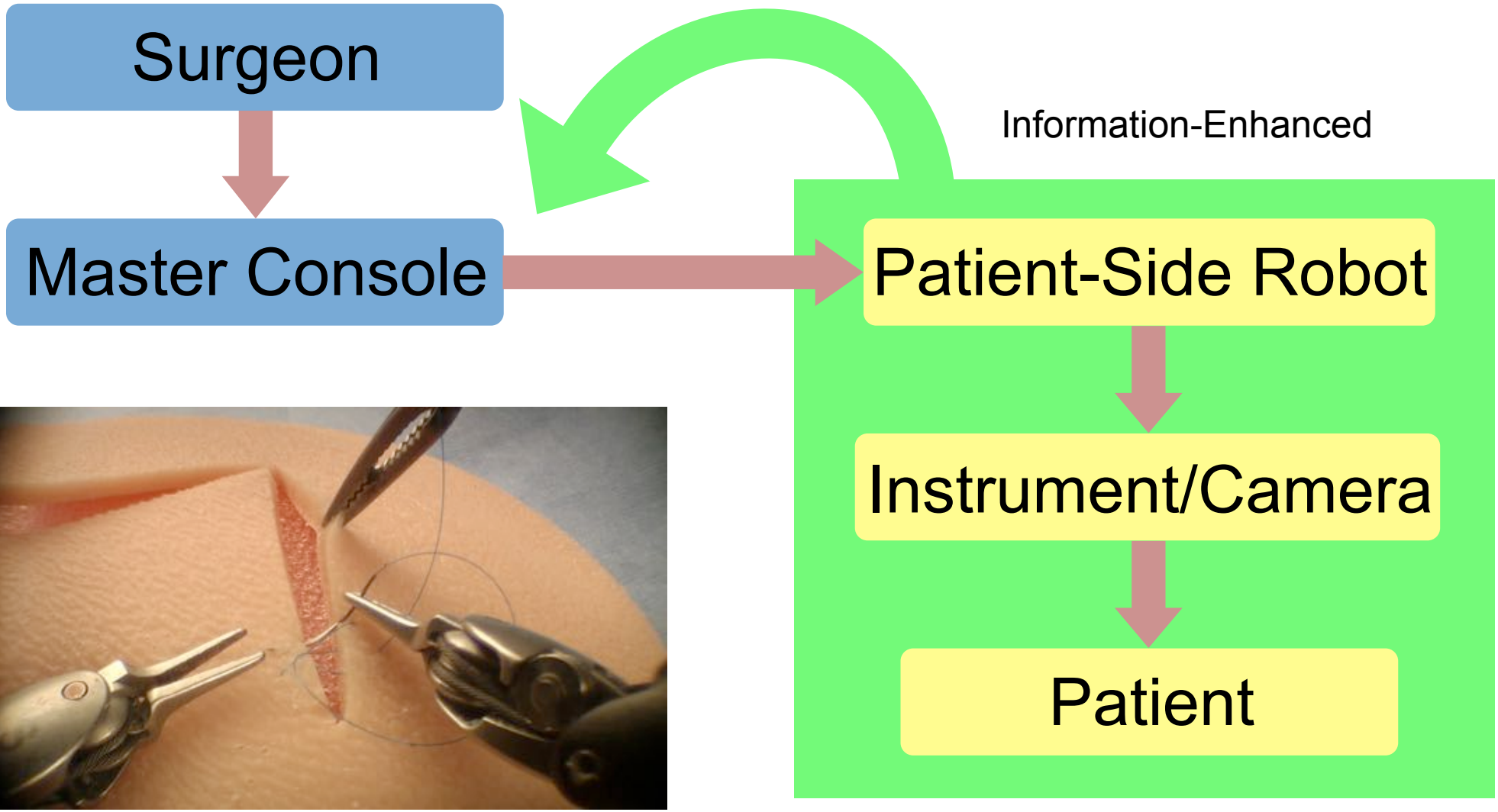
Haptics for Robot-Assisted Surgery



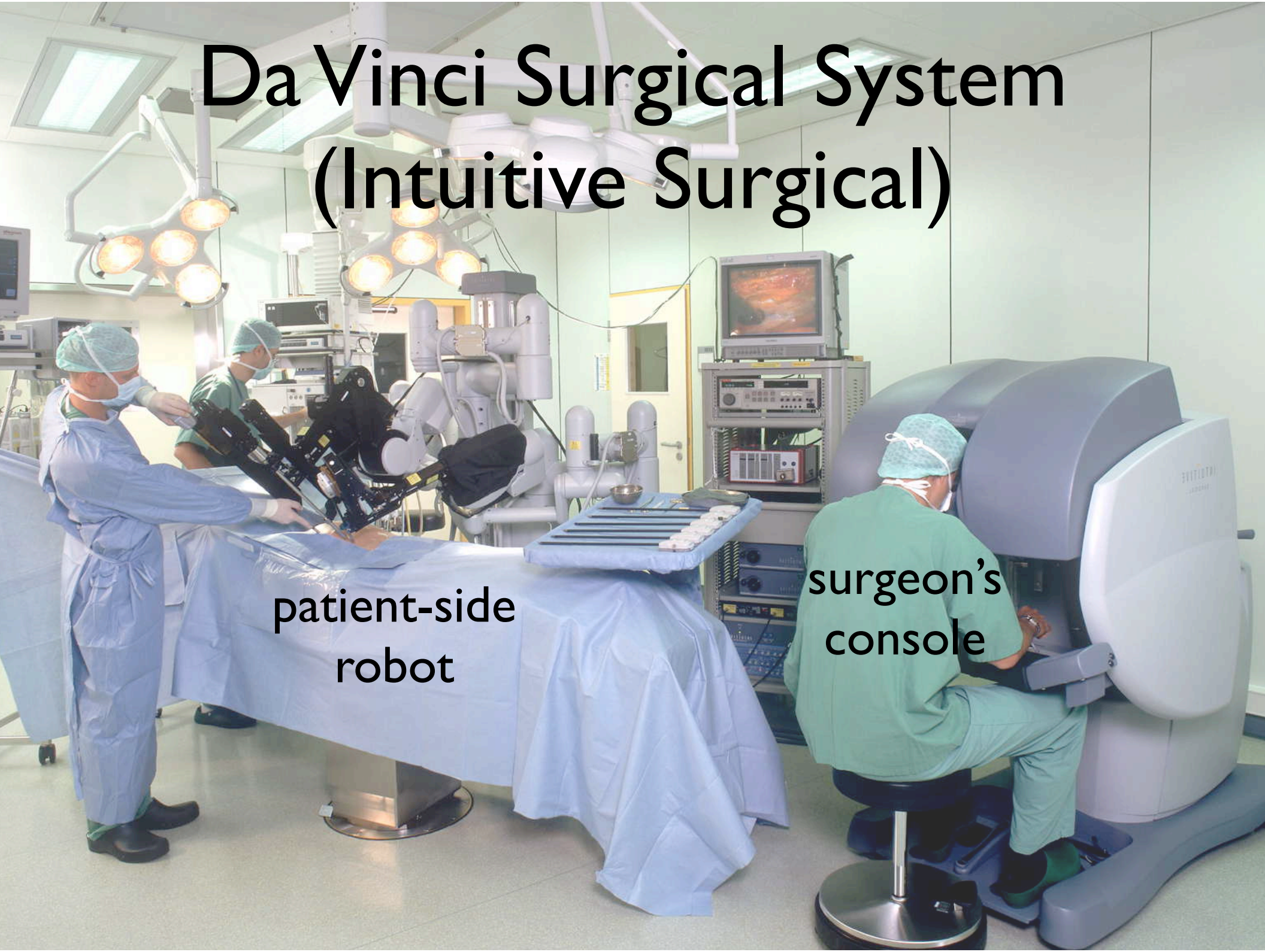
Minimally Invasive Surgery

Image source: www.womenssurgerygroup.com

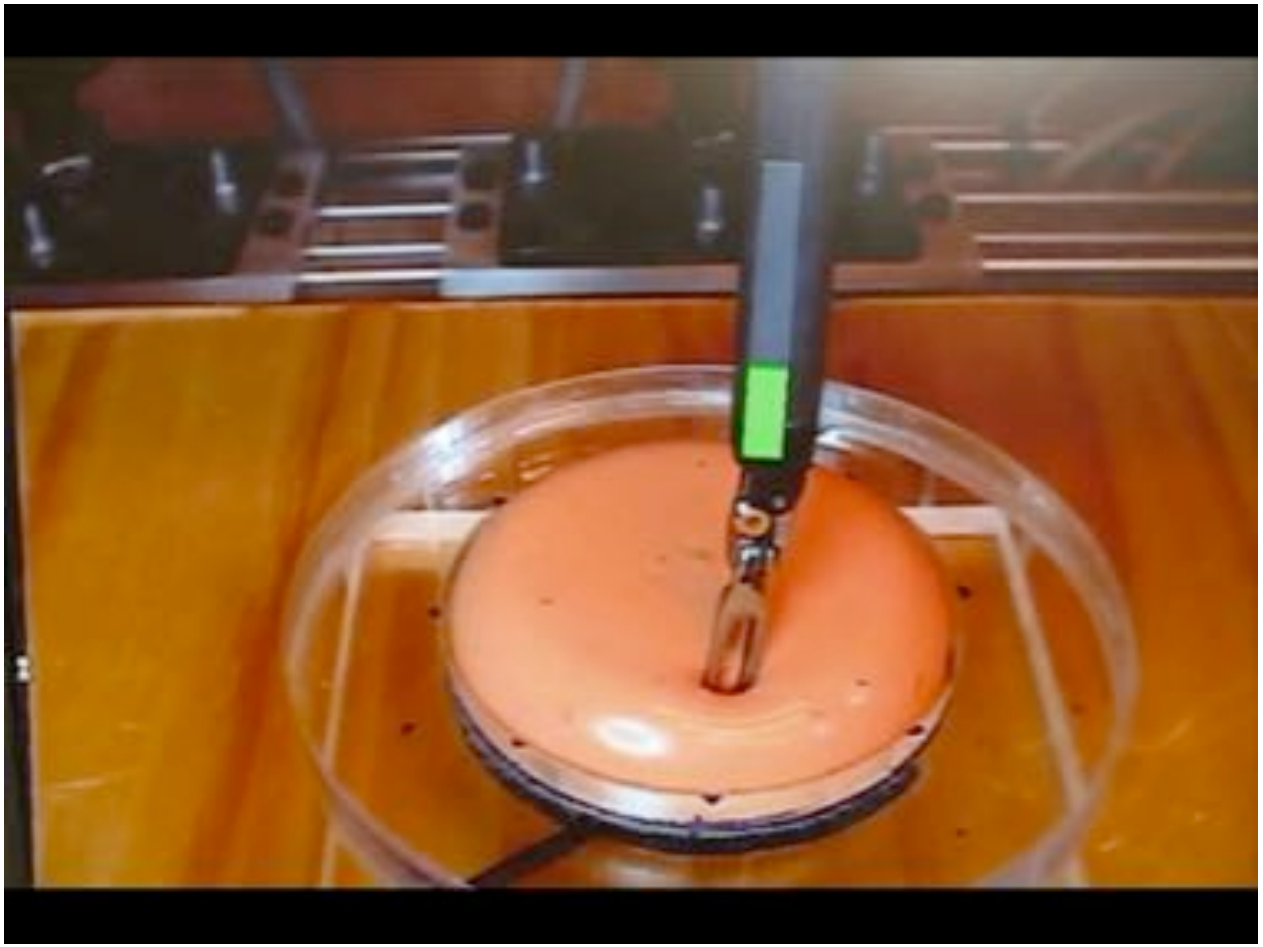
Teleoperated Robot-Assisted Minimally Invasive Surgery

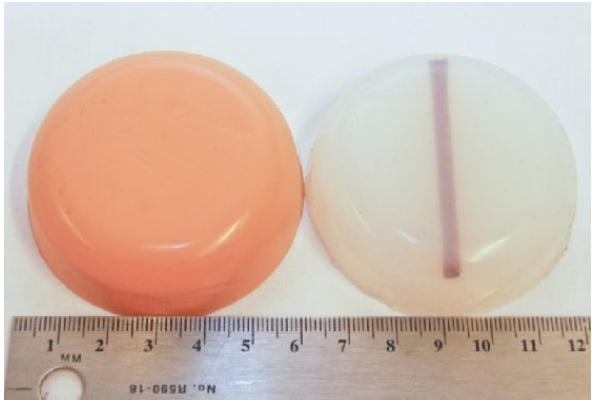


Da Vinci Surgical System (Intuitive Surgical)



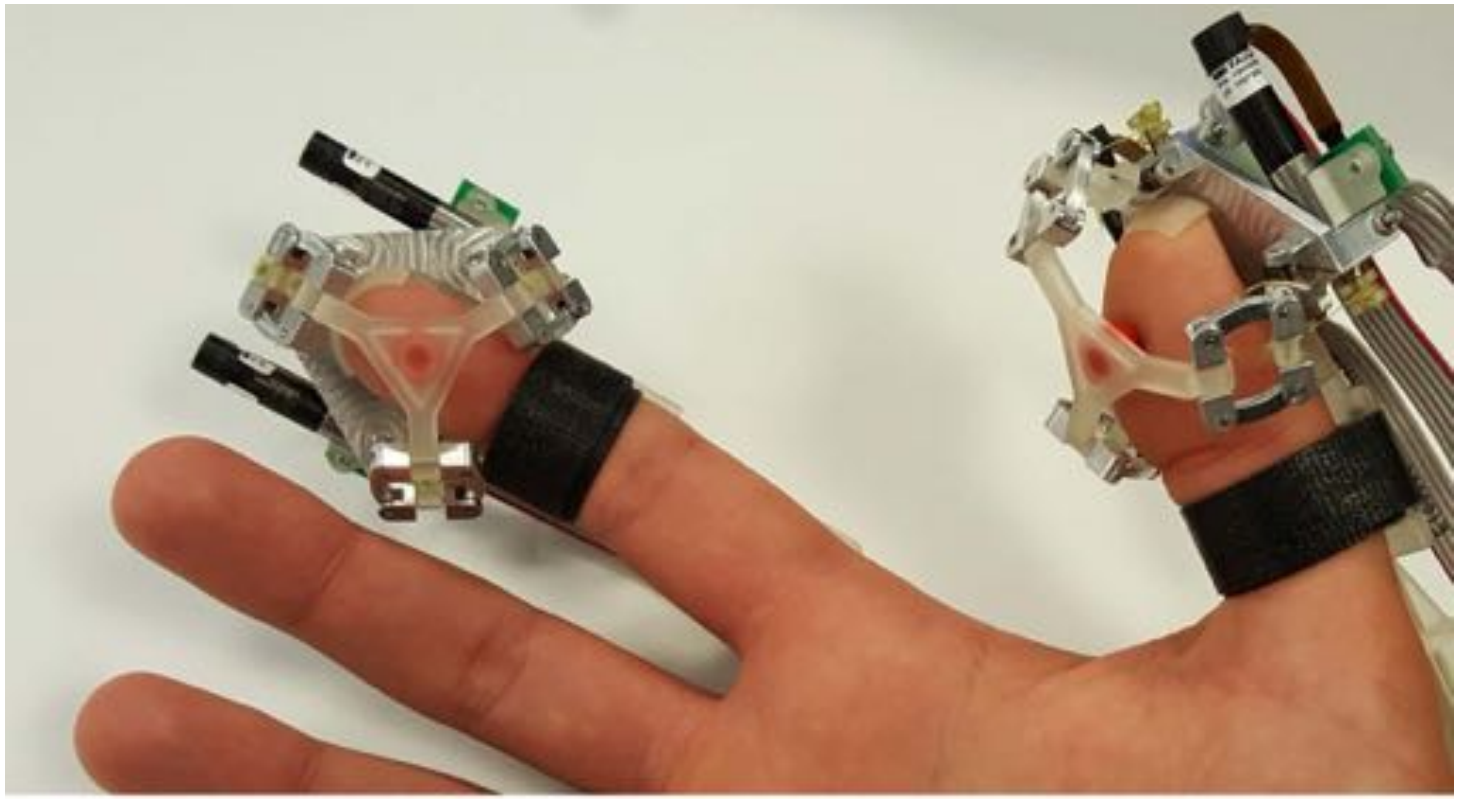
Force feedback: haptics and graphics



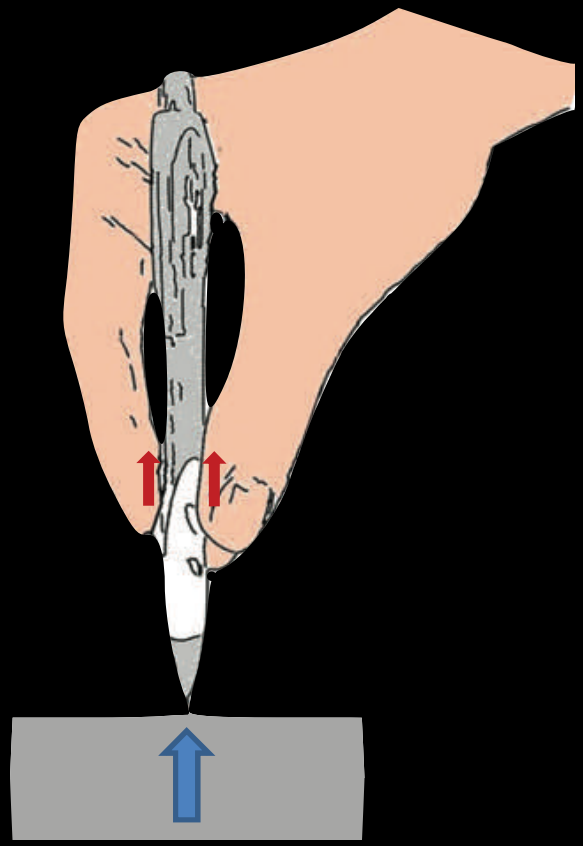


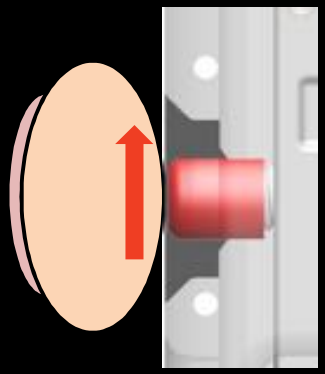
Jim Gwilliam and Mohsen Mahvash

Fingertip Haptics



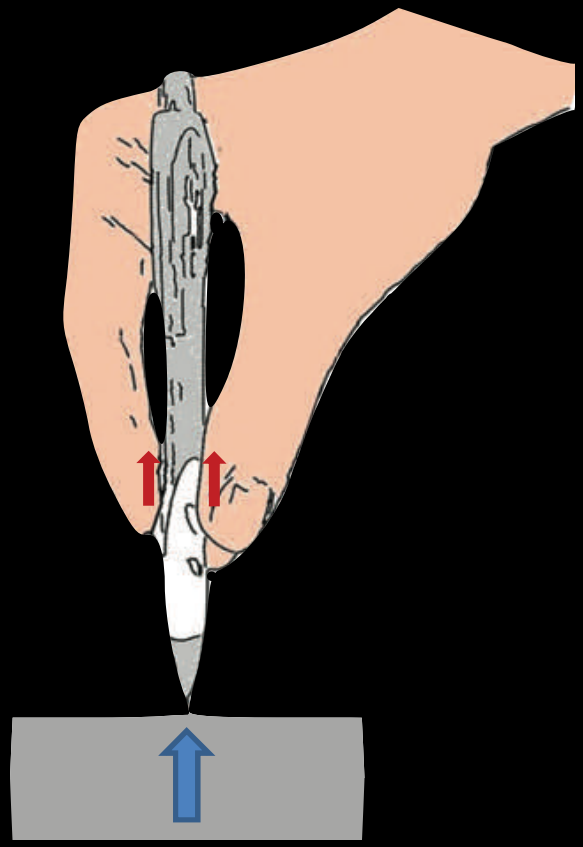
Skin stretch haptic device

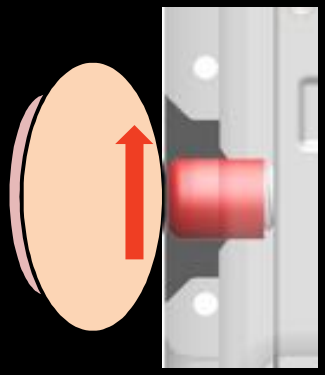


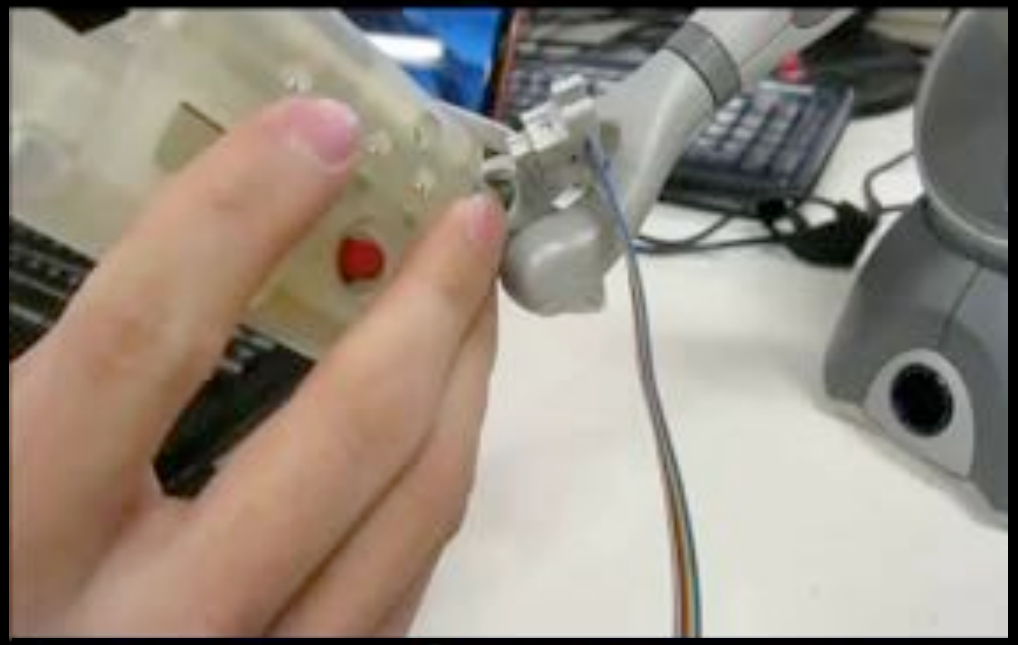


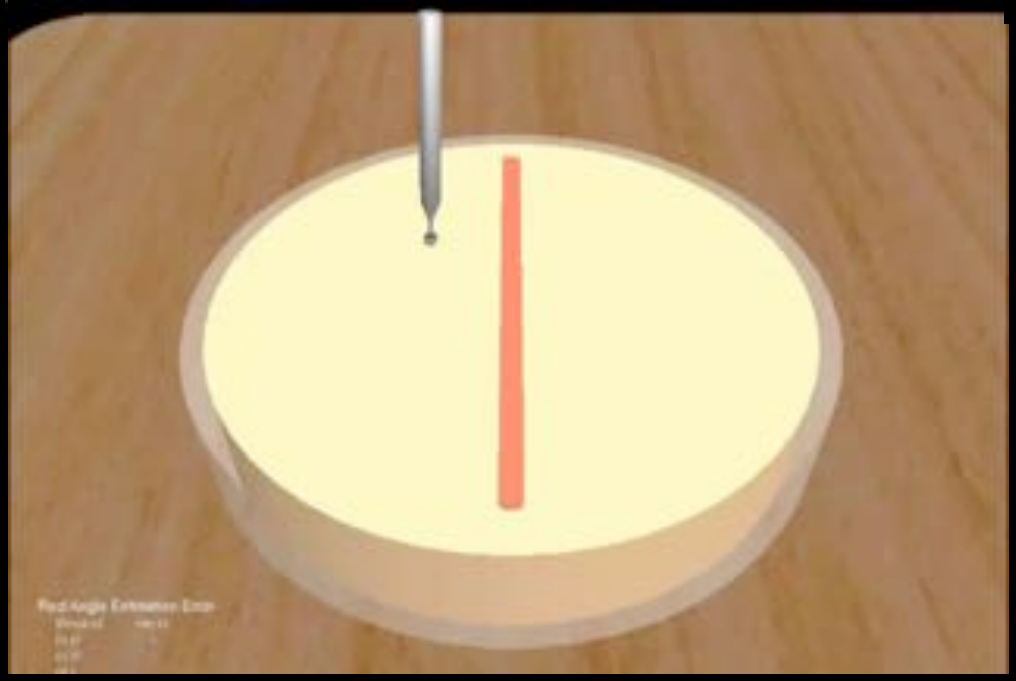
Zhan Fan Quek, Sam Schorr, Ilana Nisky, William Provancher

Skin stretch haptic device

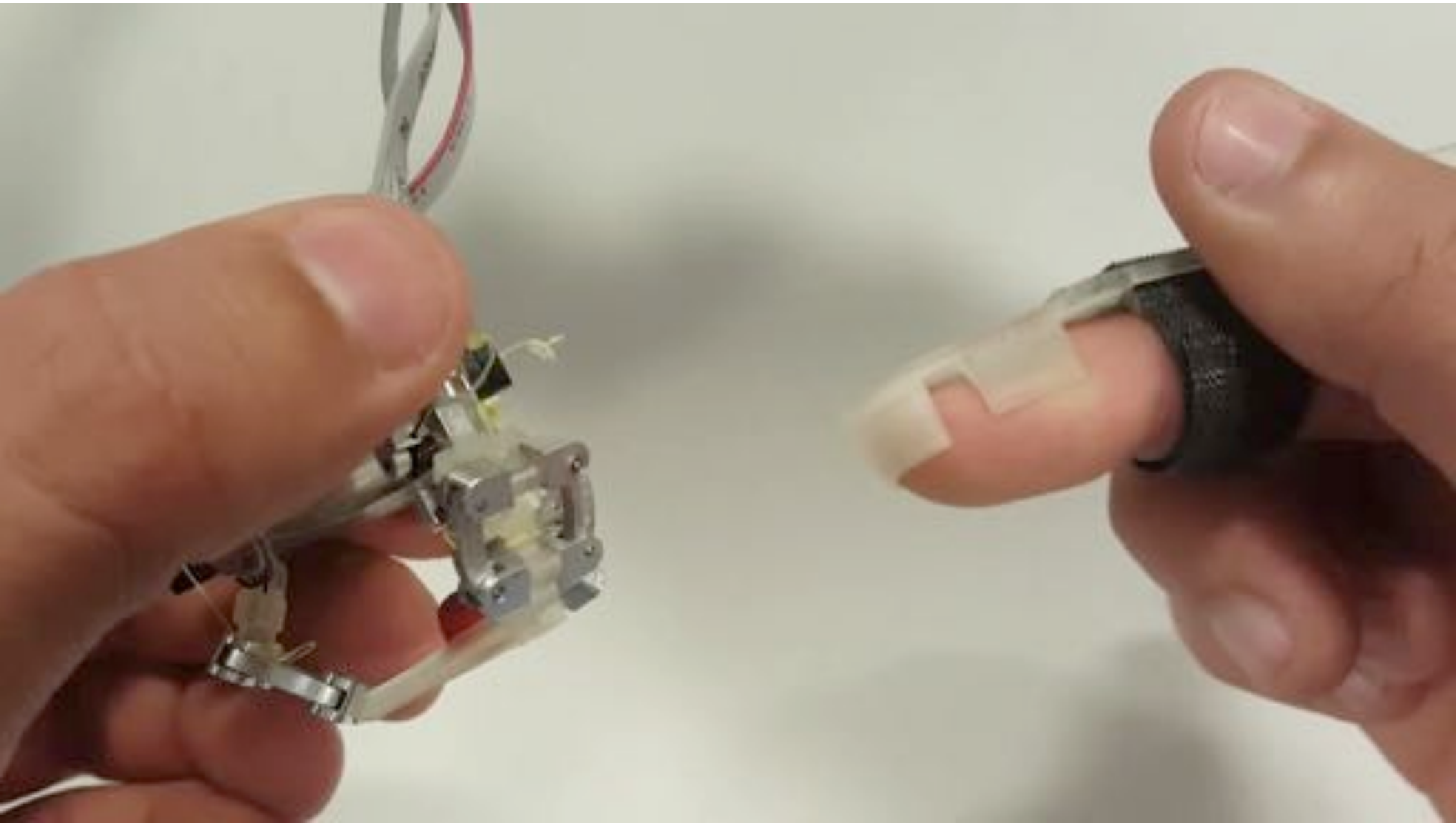








Sam Schorr, Zhan Fan Quek, Ilana Nisky, William Provancher

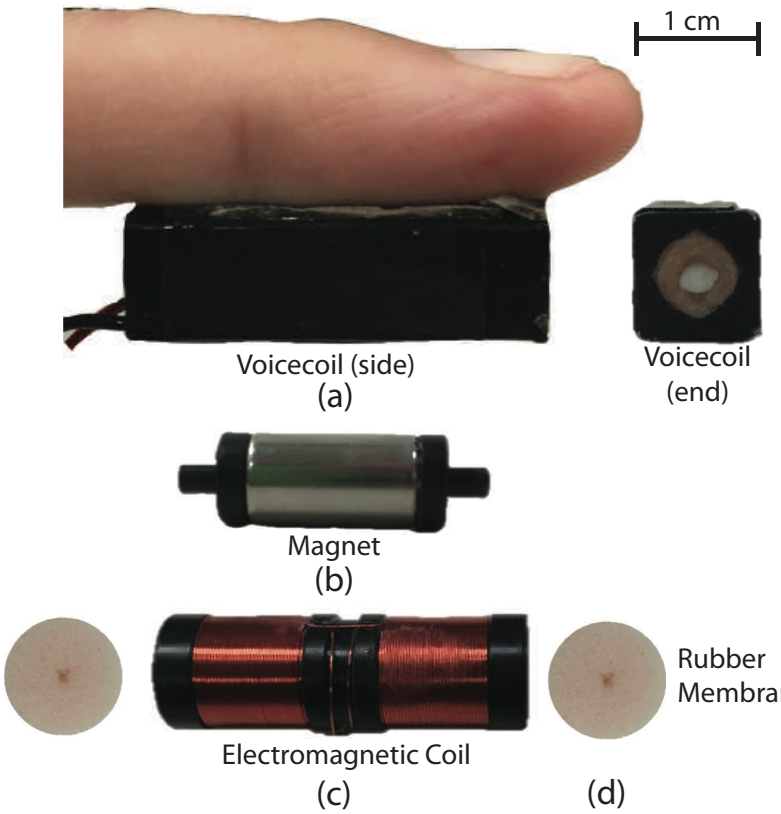


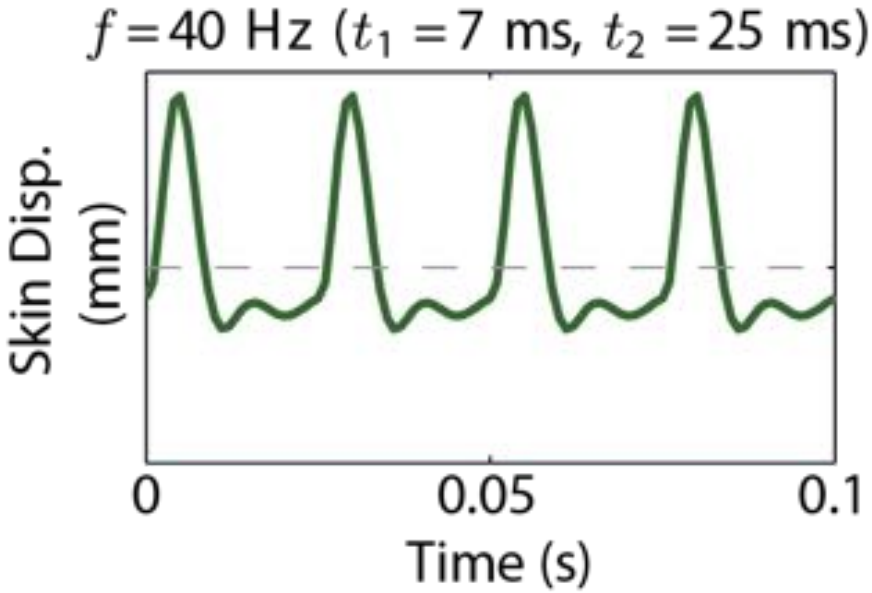
Sam Schorr

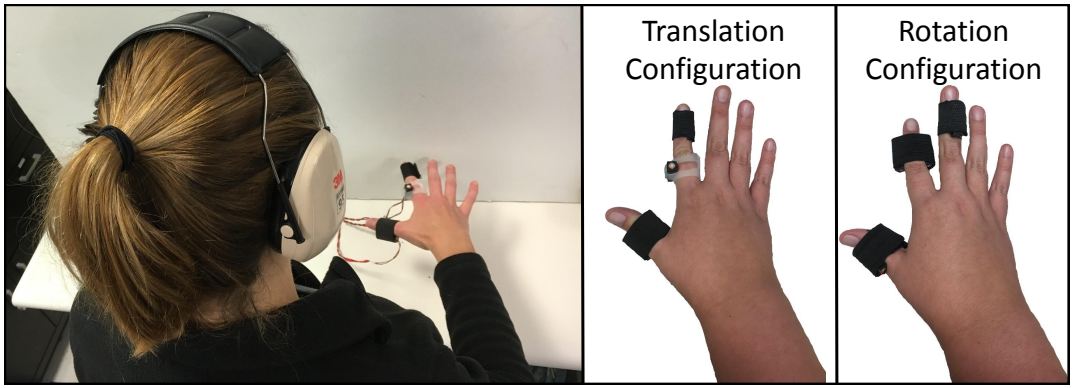
Mass Perception

Jacob Suchoski

Asymmetric Vibrations

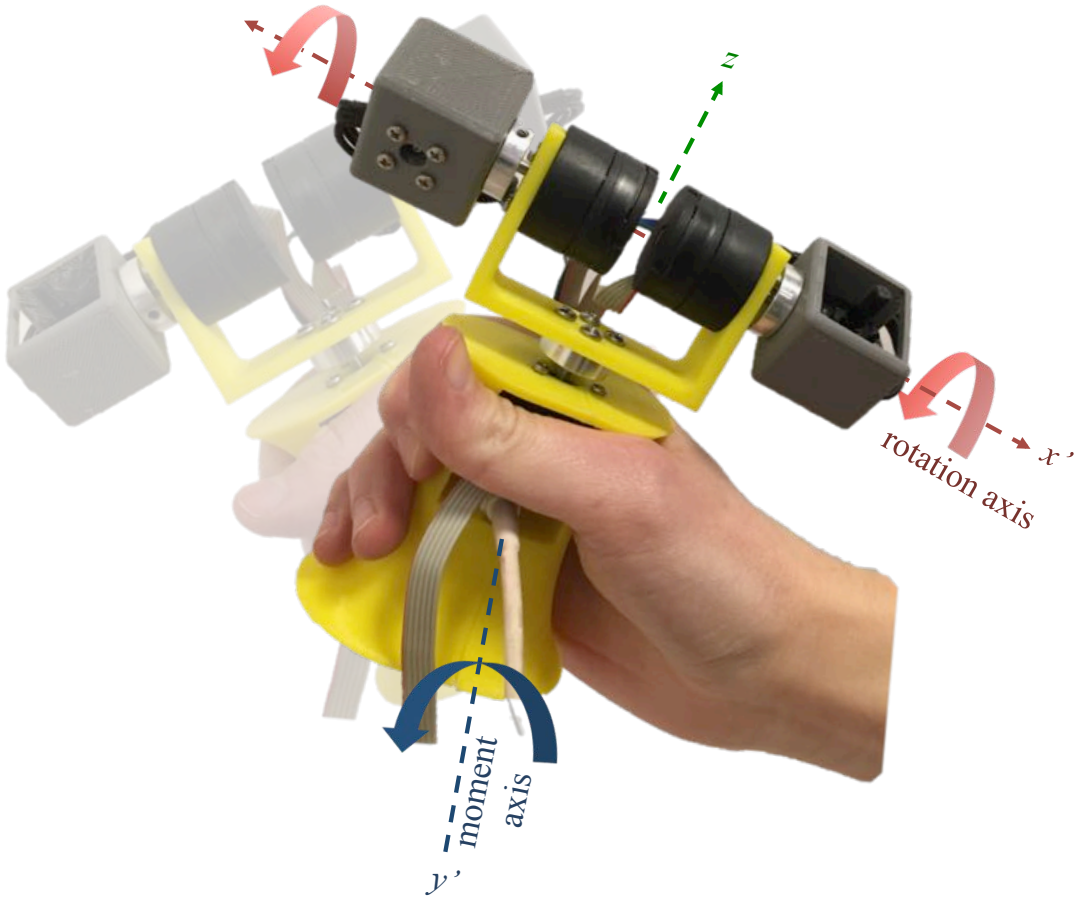


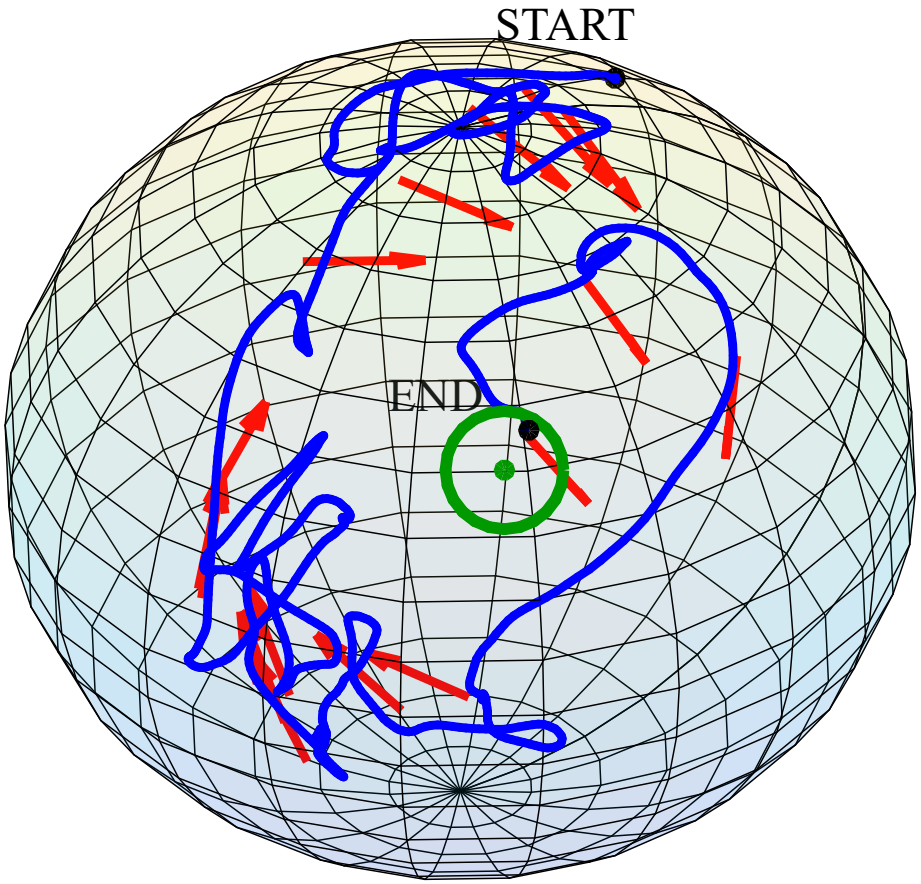




Heather Culbertson, Julie Walker, Michael Raitor

Reaction Wheels

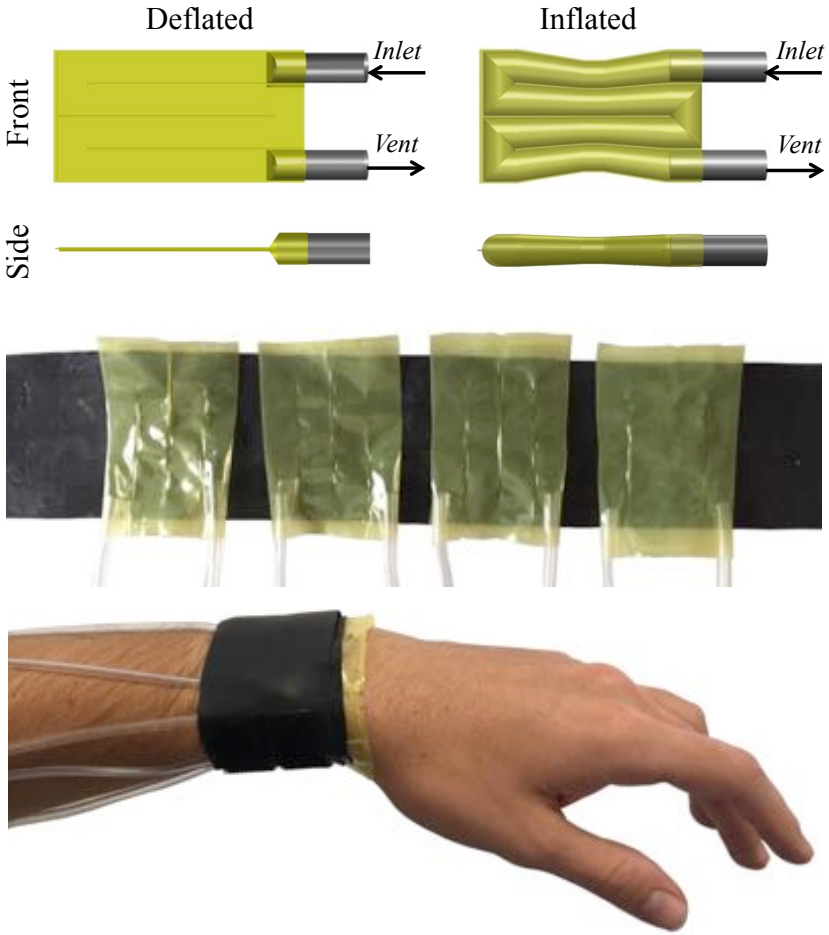


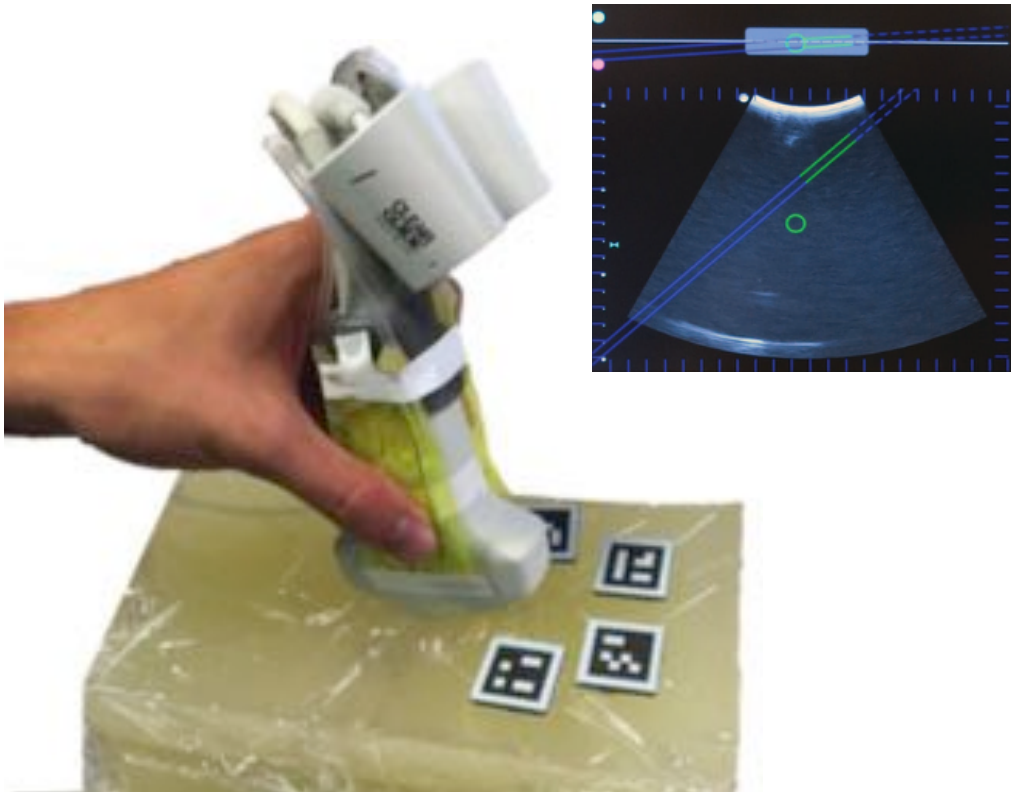


Julie Walker, Michael Raitor, Heather Culbertson

Pneumatics

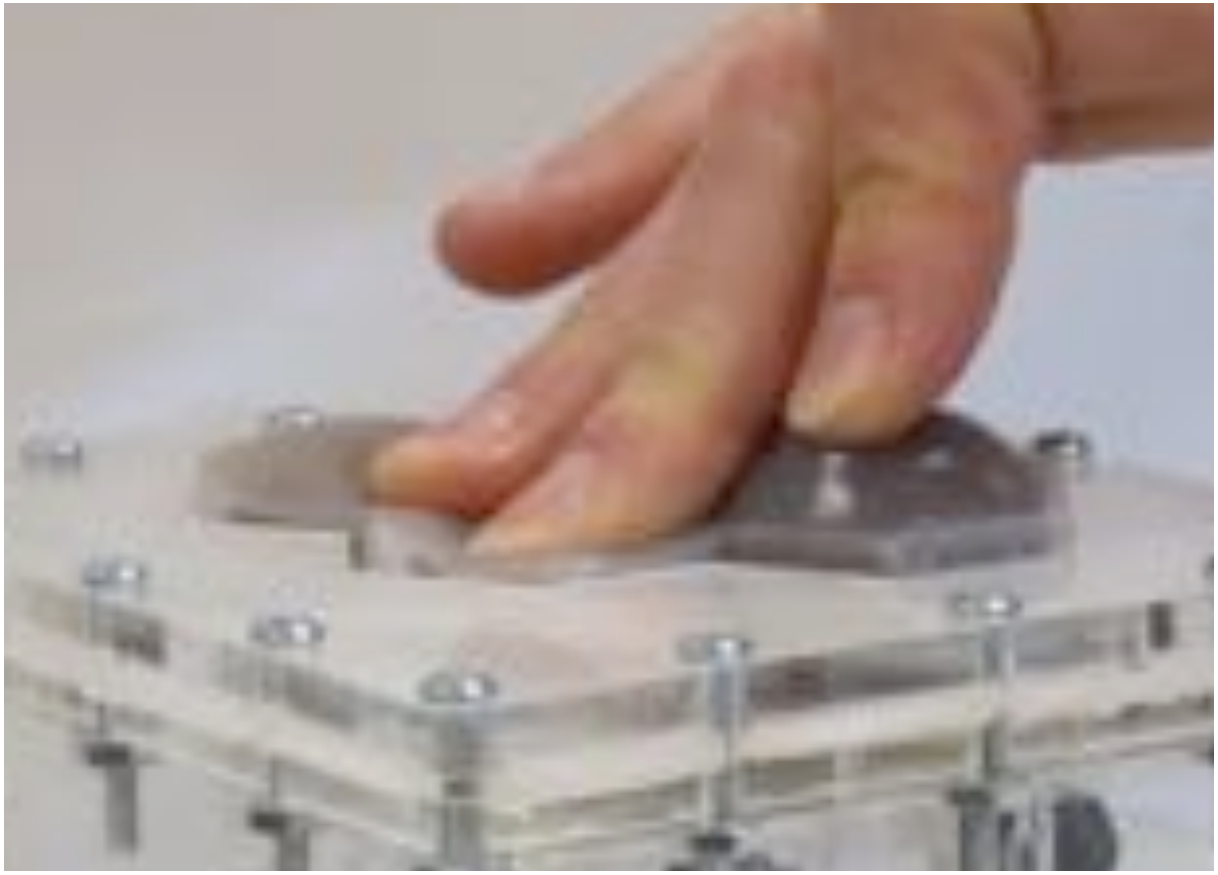
WRAP: Wearable, Restricted-Aperture Pneumatics for Haptic Guidance





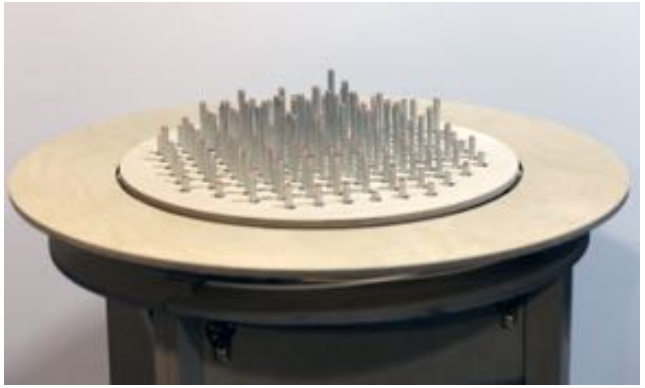
Michael Raitor, Heather Culbertson, Julie Walker

Active Surfaces

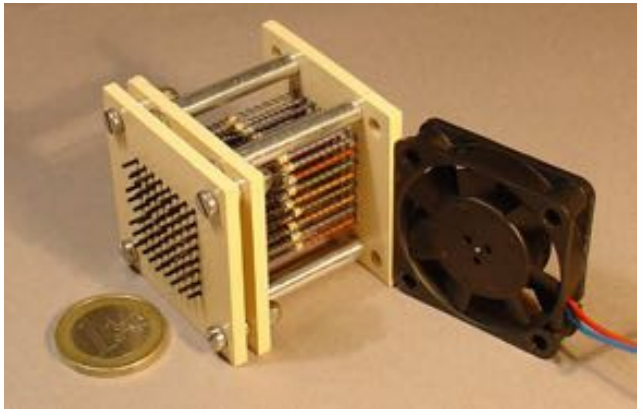


Pin Arrays

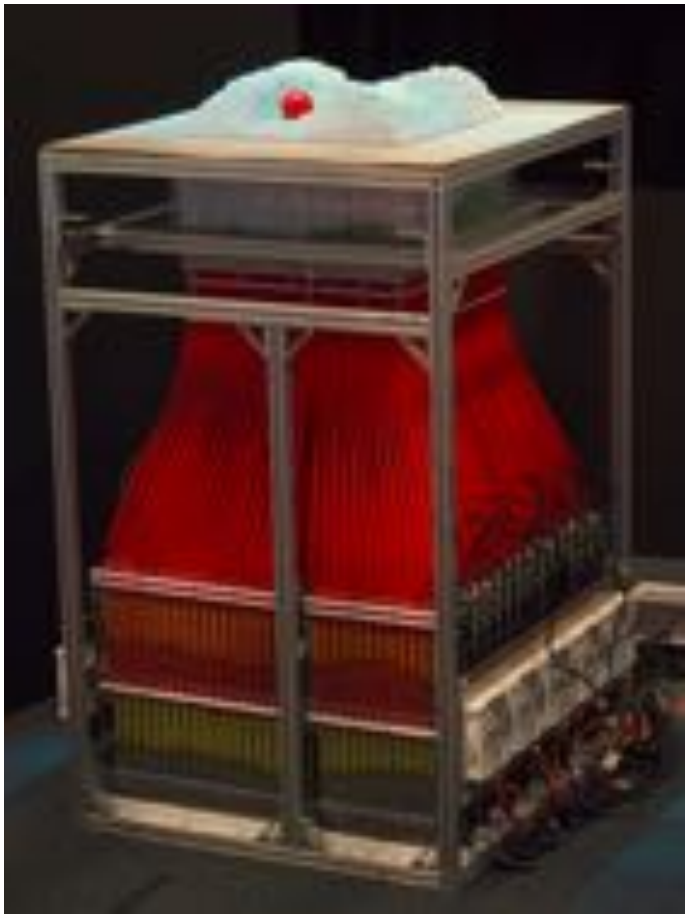
Iwata et al. 2001



Leithinger et al. 2010

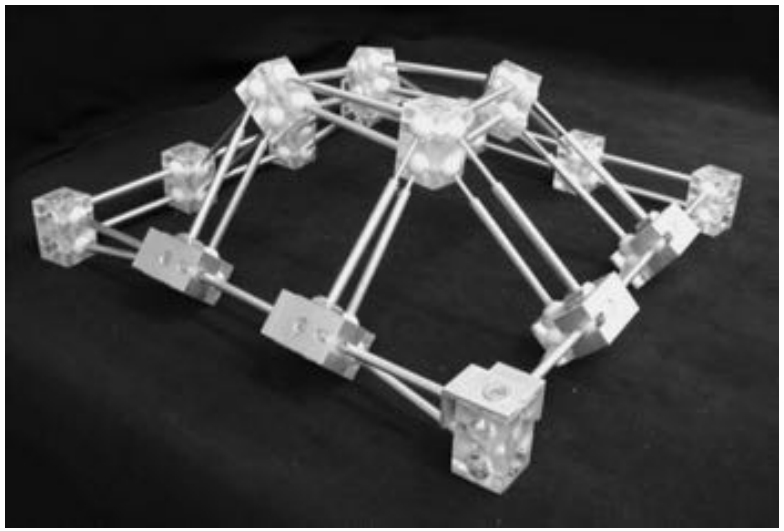


Velazquez et al. 2005



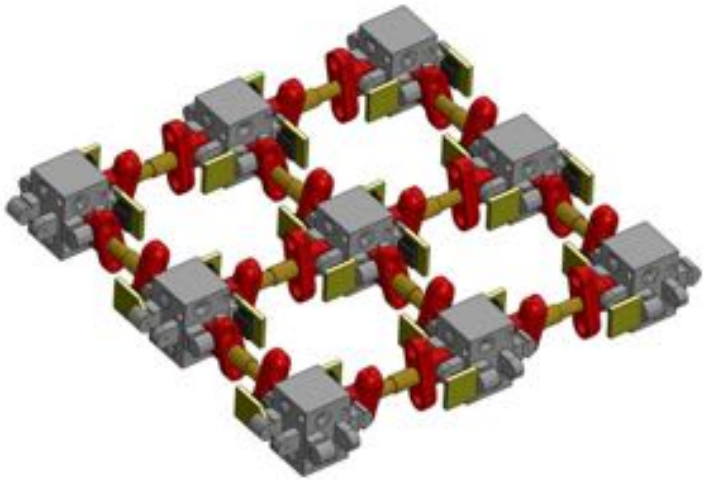
Follmer et al. 2013

Deformable Crusts



Mazzone et al. 2003

Mazzone et al. 2004

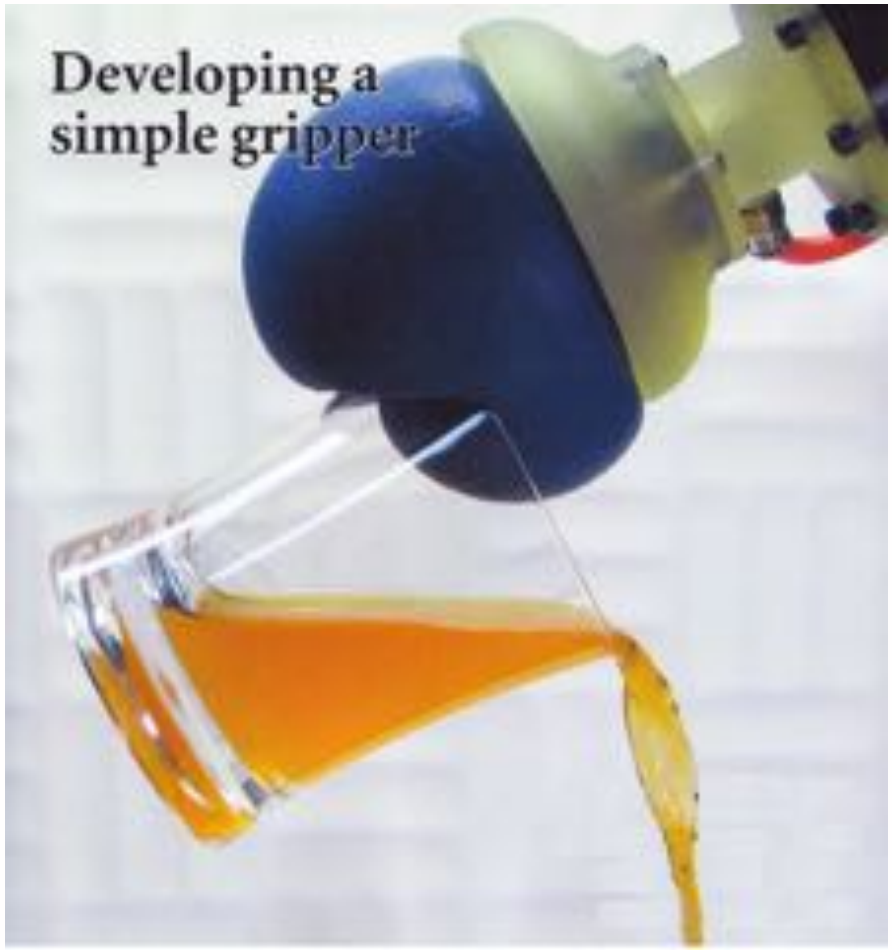


Klare et al. 2013

Follmer et al. 2012

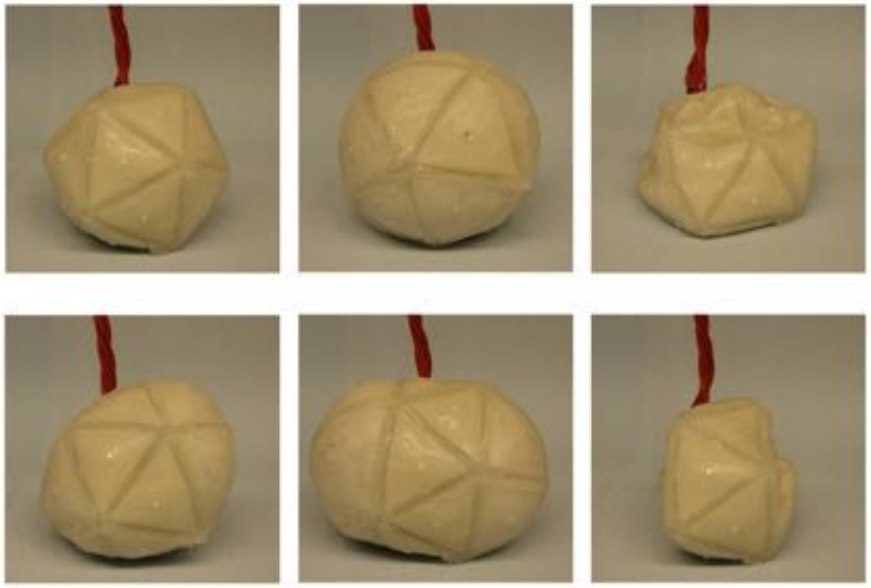
Stanley et al. 2012

Particle Jamming



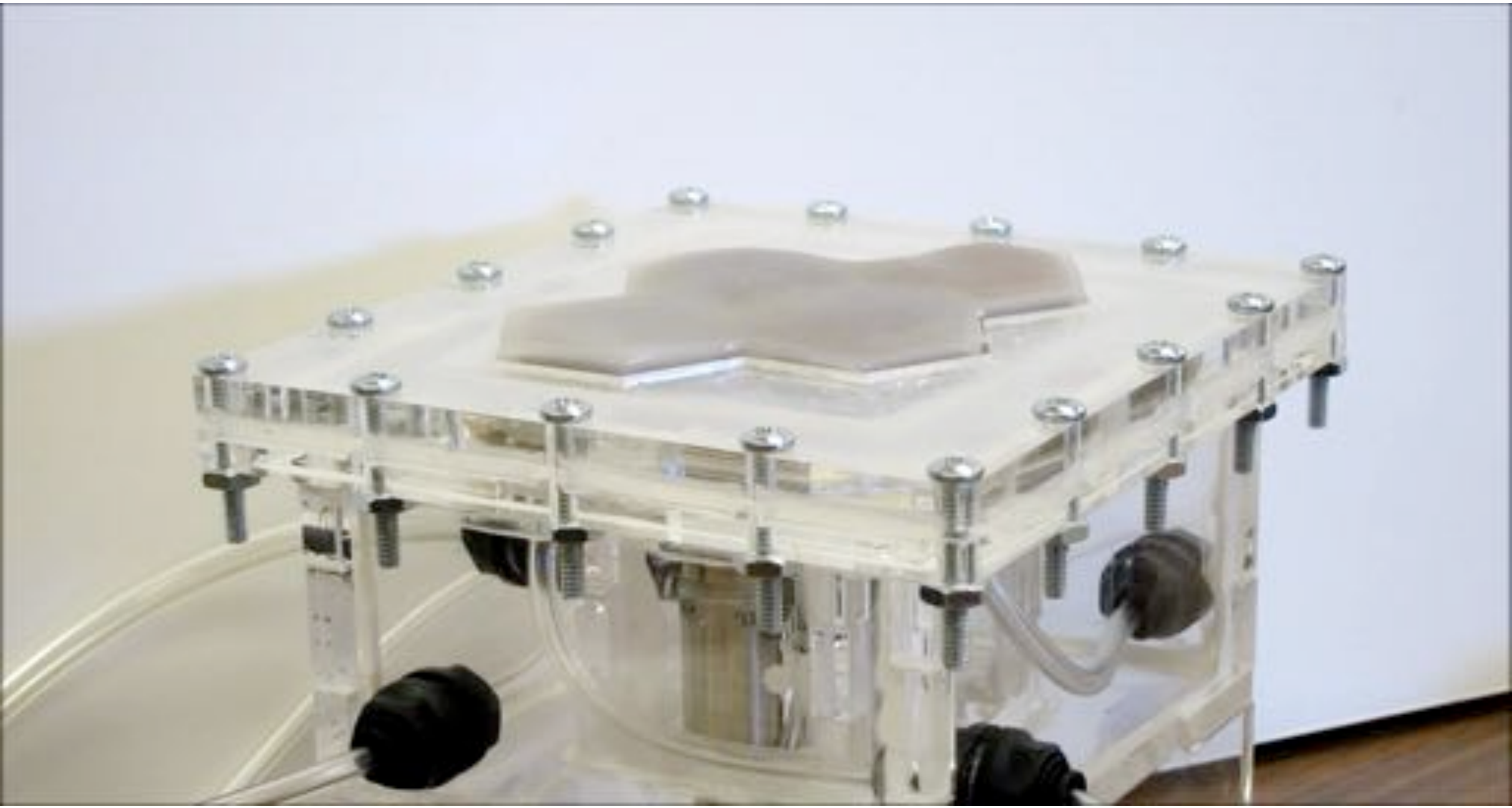
Brown et al. 2010

Cheng et al. 2012



Steltz et al. 2009

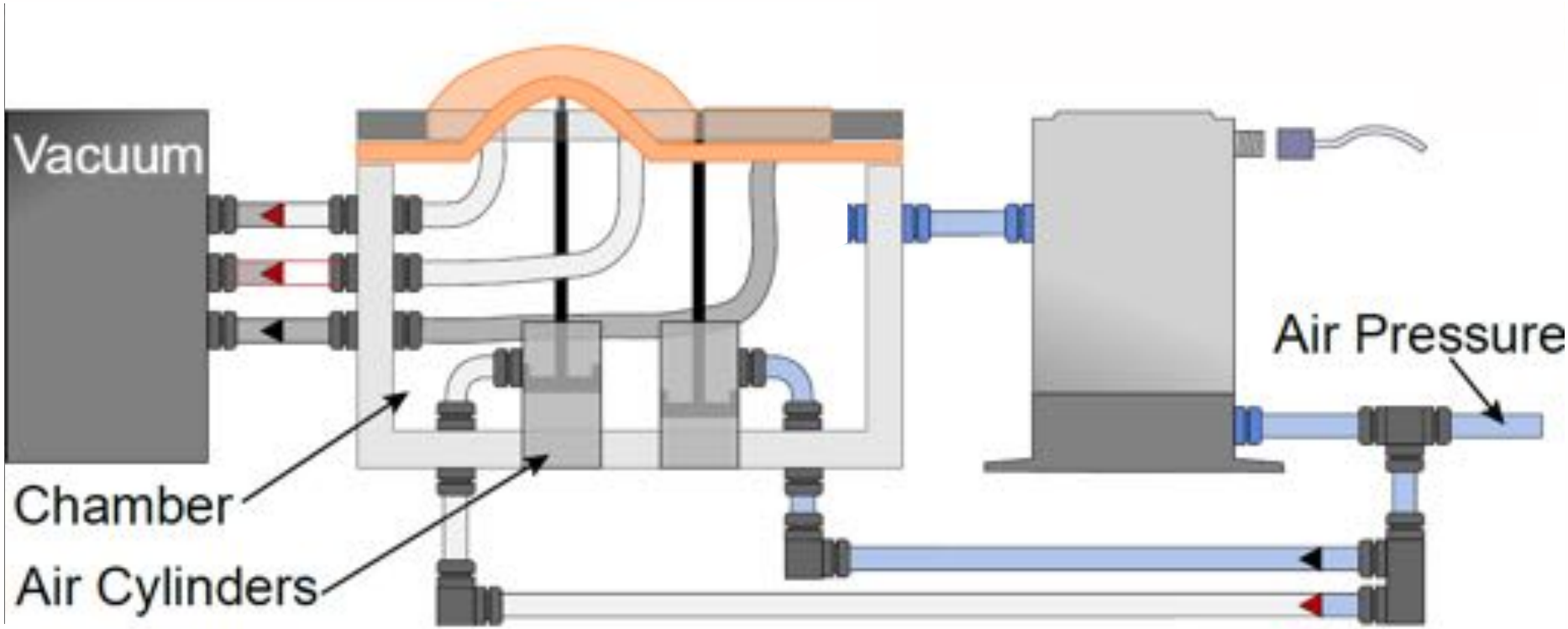
Haptic Jamming: Four-Cell Surface



Stanley, et al. 2013

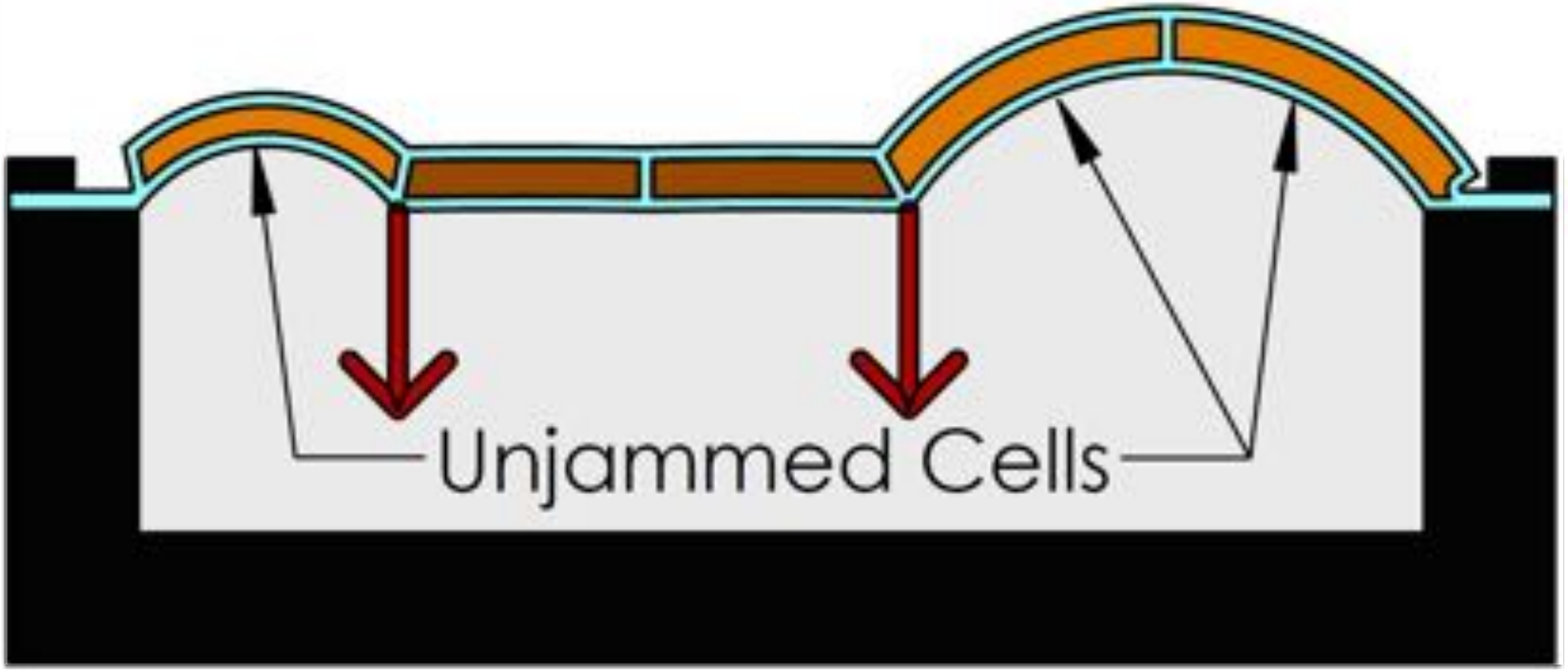
Video is real time

Haptic Jamming Actuation

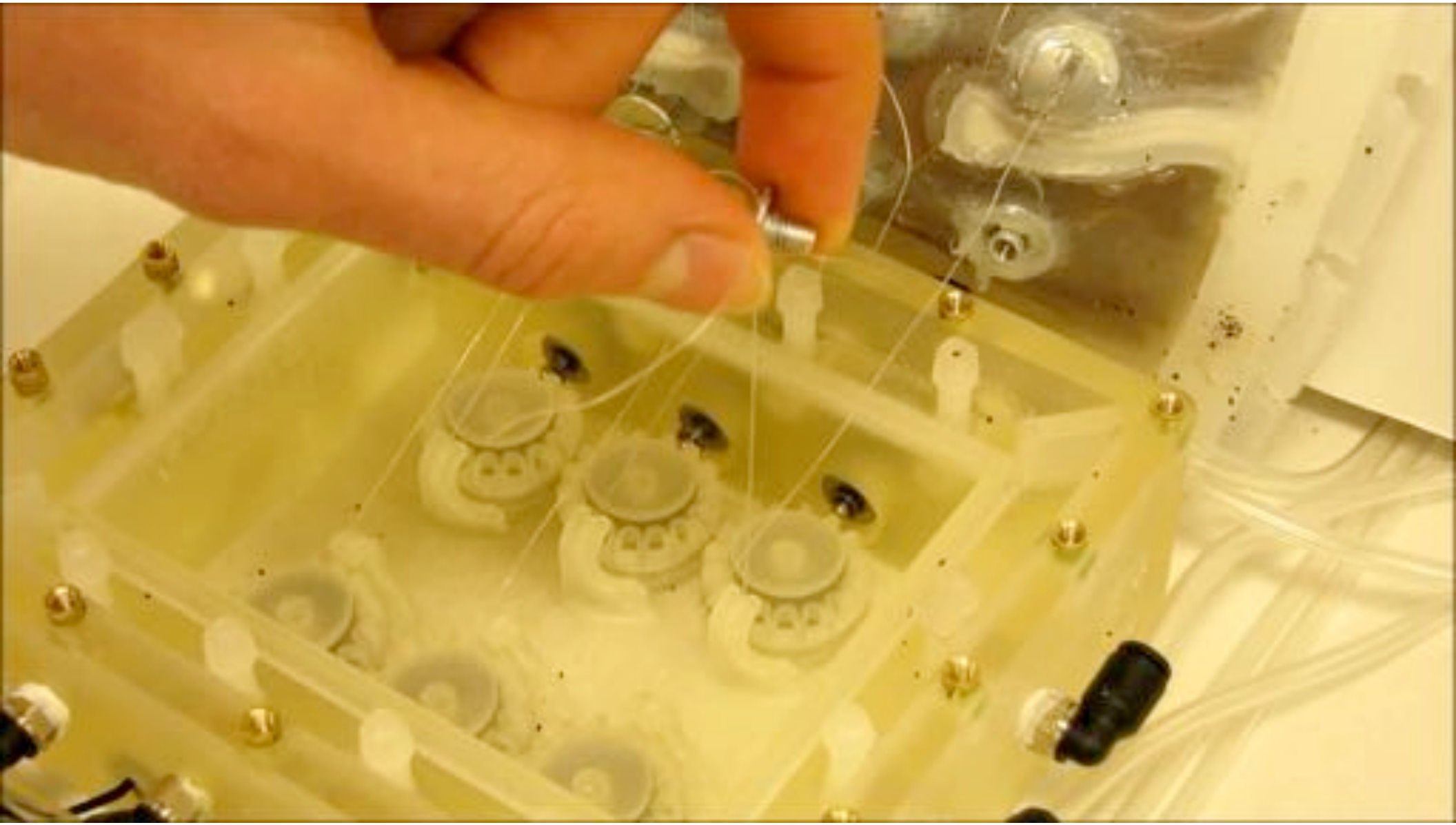


Stanley, et al. 2013

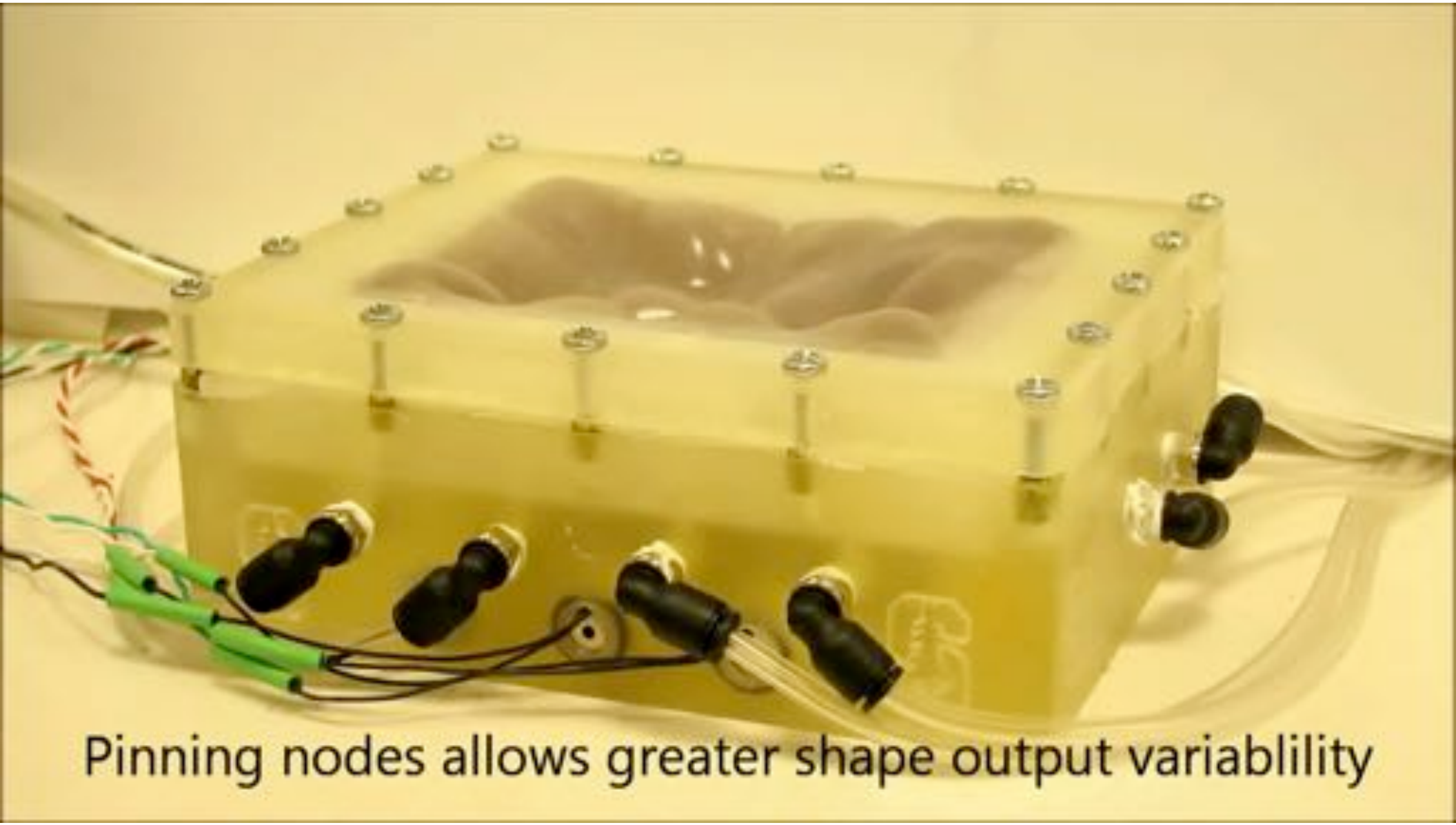
Haptic Jamming Actuation



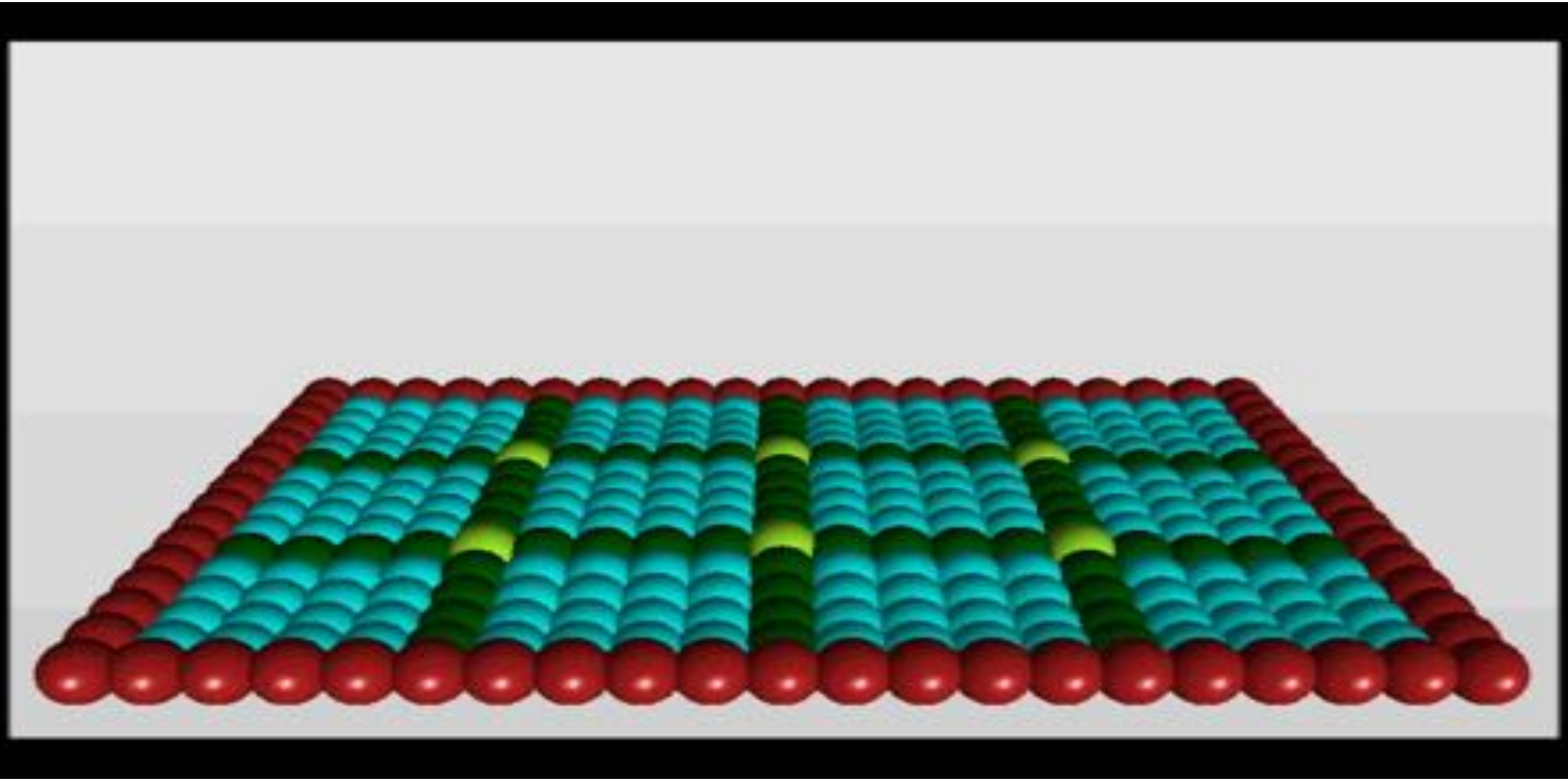
Node Pinning



12-Cell Array



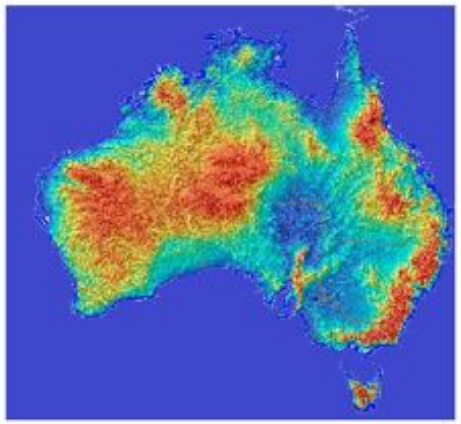
Shape Simulation



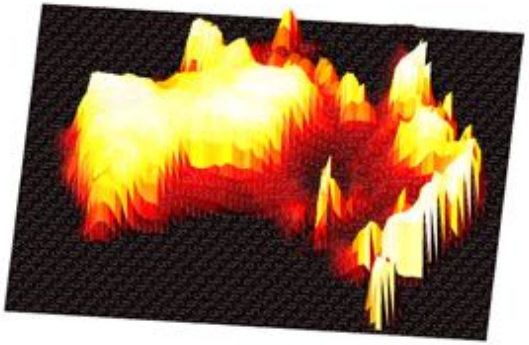
Stanley and Okamura, 2016

Shape Simulation

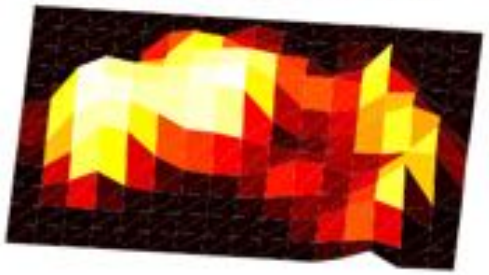
Original 2D Image



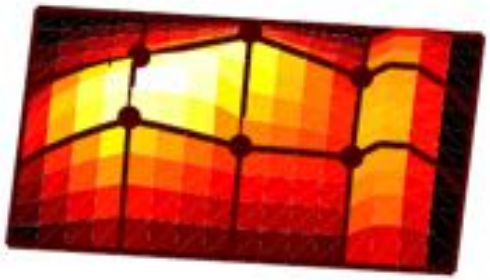
Constructed 3D Data



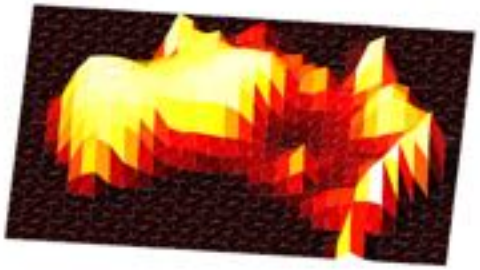
Input into 3x4 Simulator



Output from 3x4 Simulator



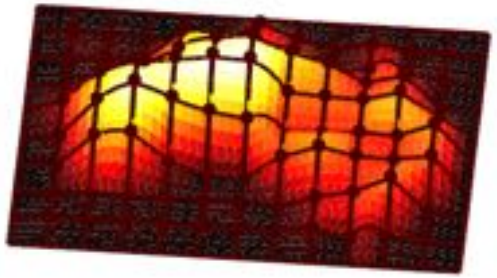
Input into 6x8 Simulator



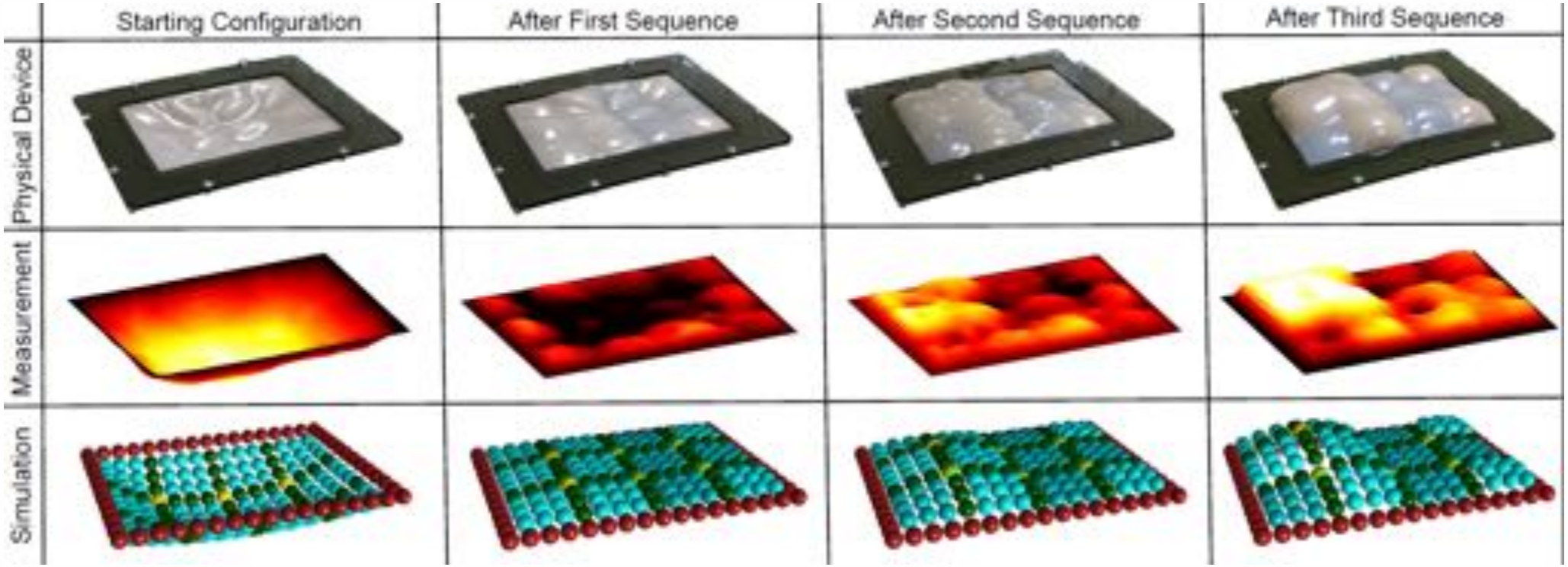
Output from 6x8 Simulator

Input into 9x12 Simulator

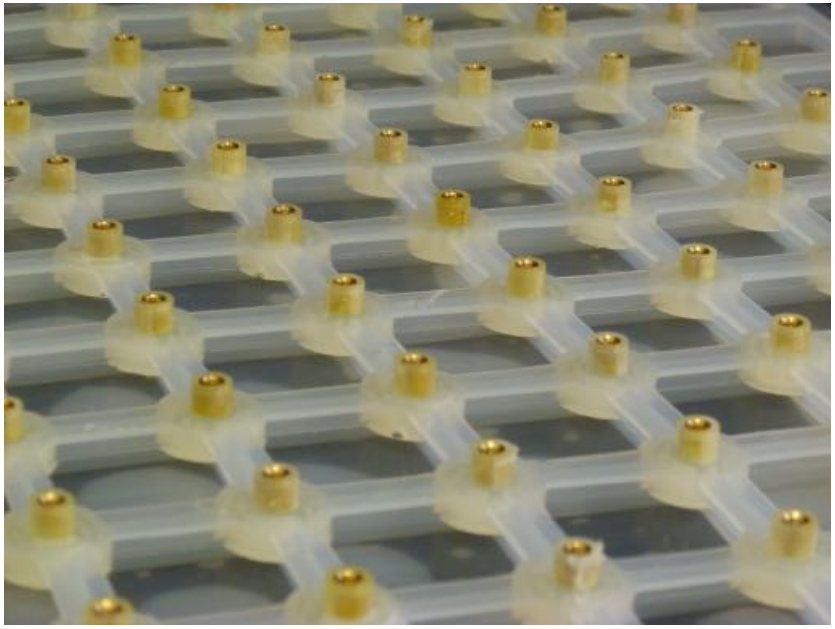
Output from 9x12 Simulator



Closed-Loop Control

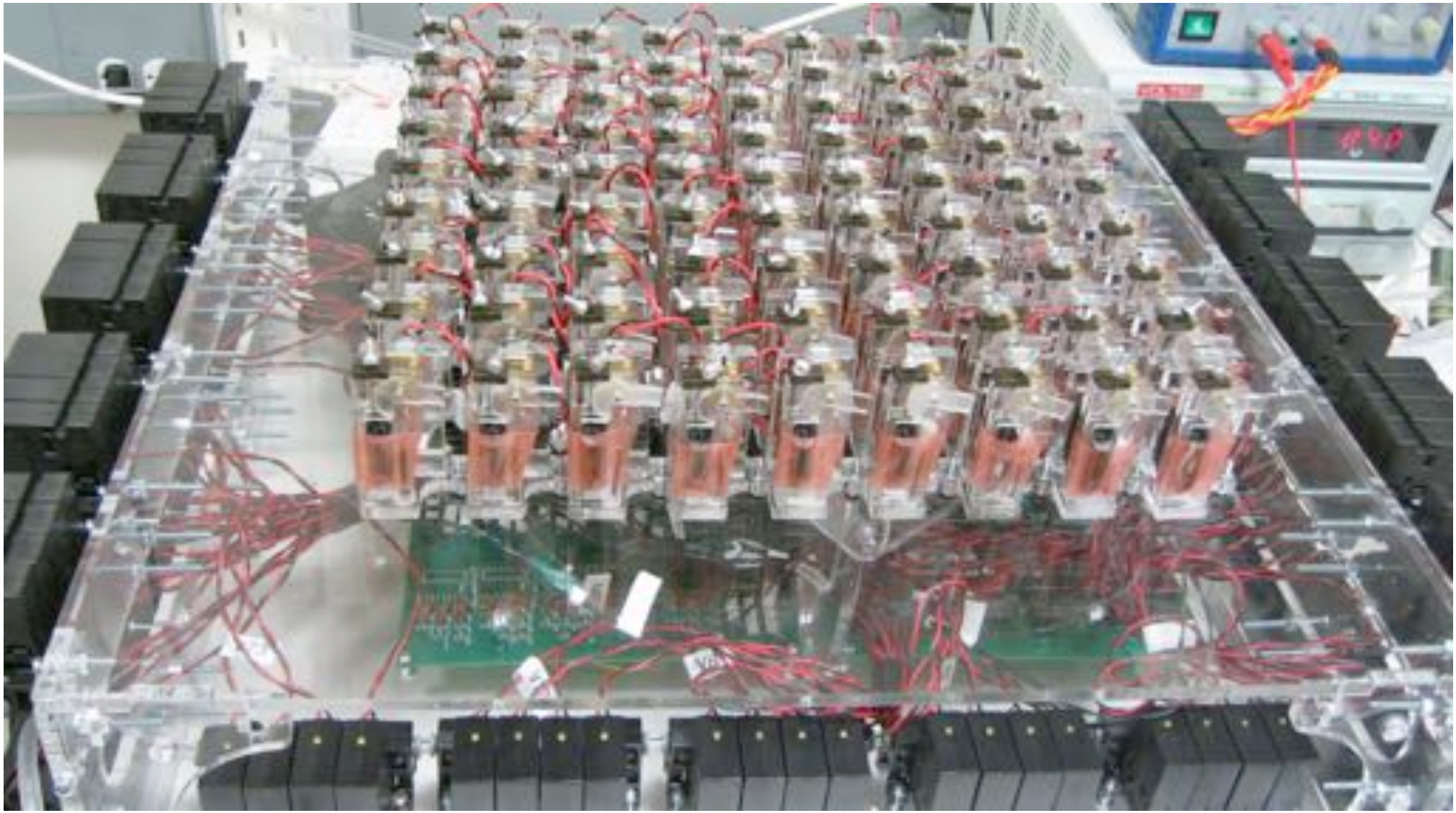


100-Cell Array



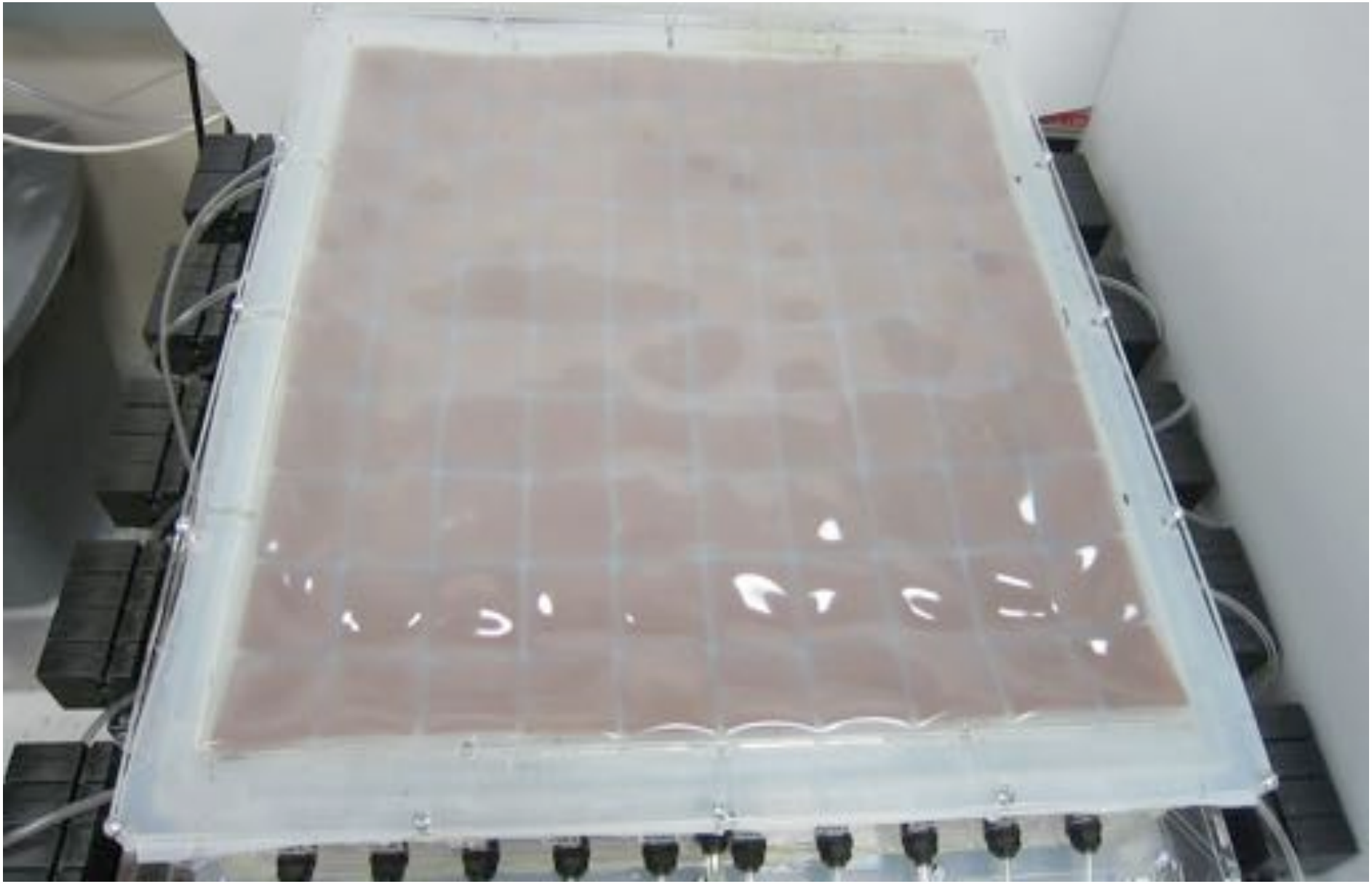
100 cells

100-Cell Array



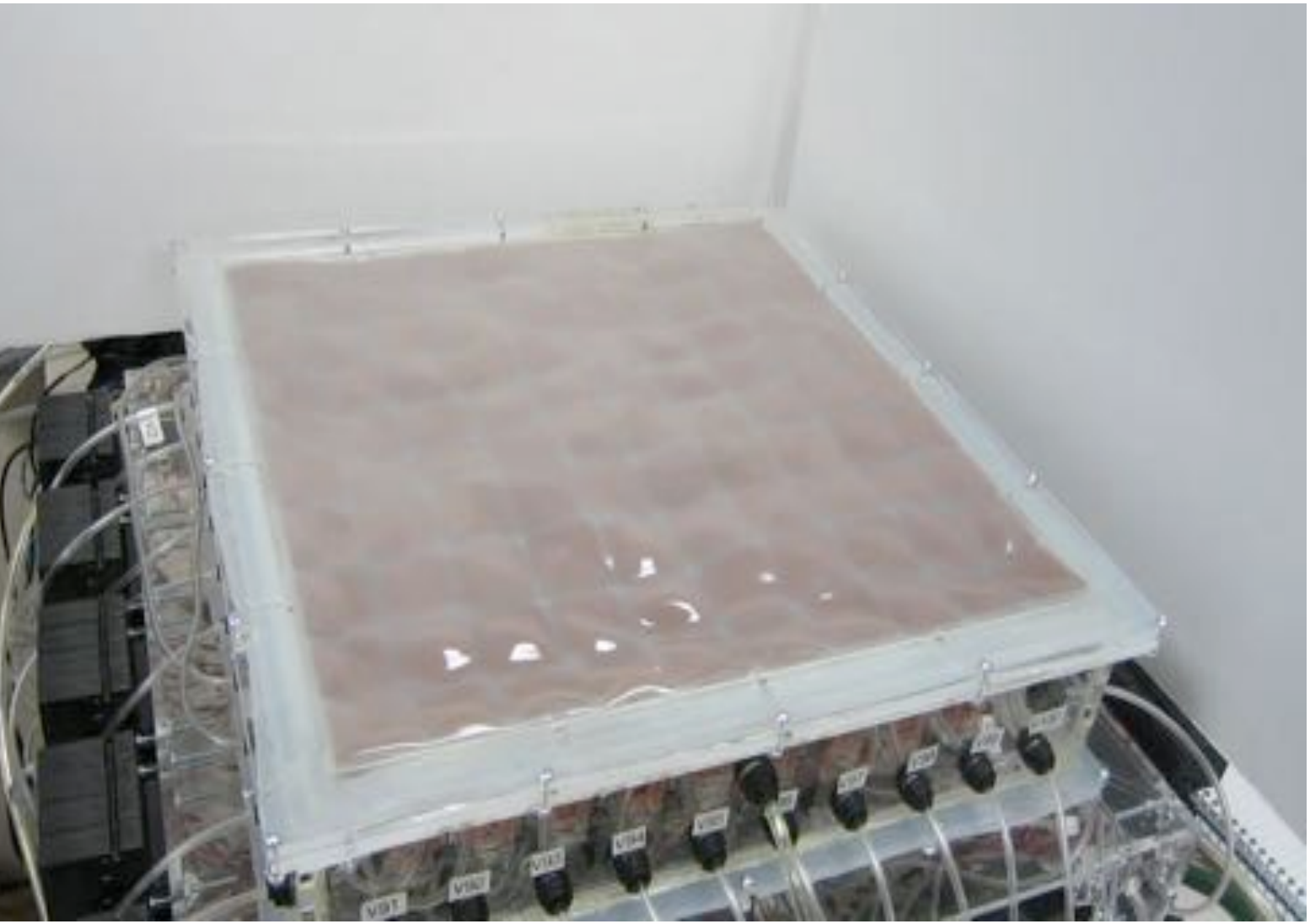
100 cells

100-Cell Array



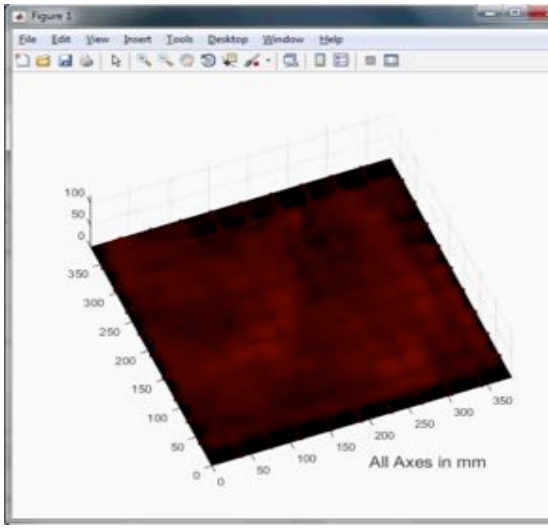
Video is real time

Closed-Loop Control

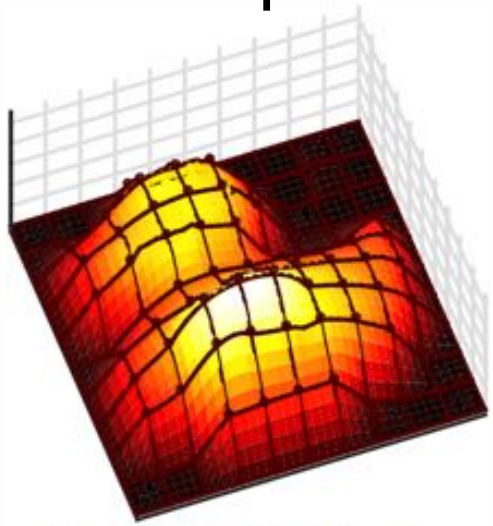


Video is real time

Measured Output

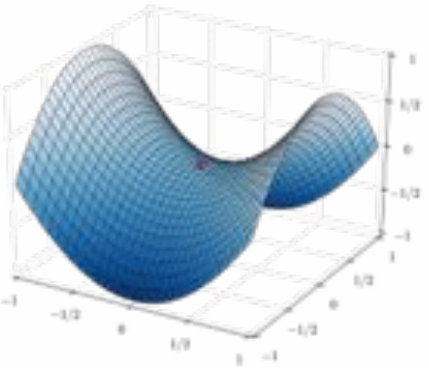


Simulated Output



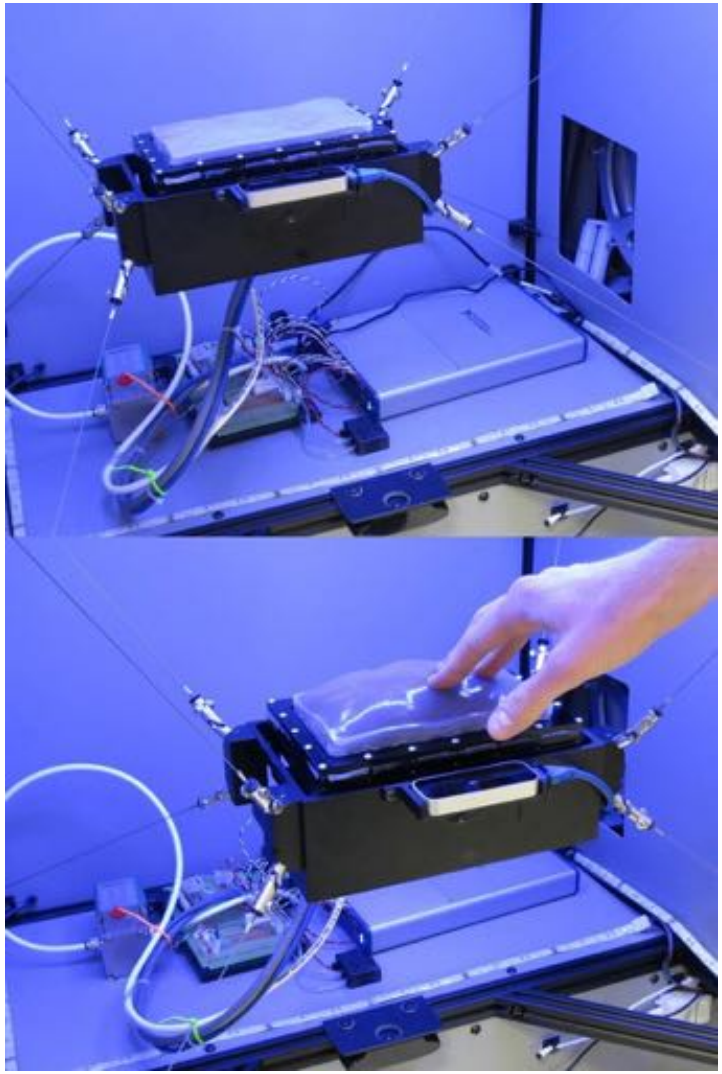
Some envisioned applications

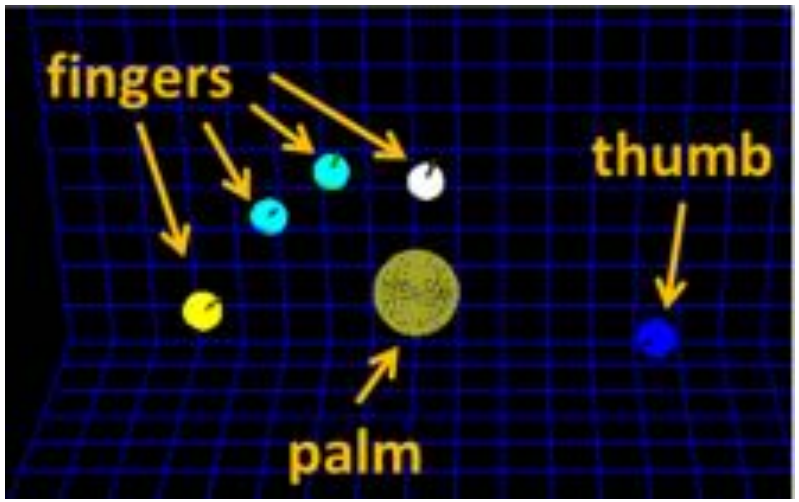
- Design
- Consumer
- Medical
- Assistive Technology
- Changeable Product
- Wearable!

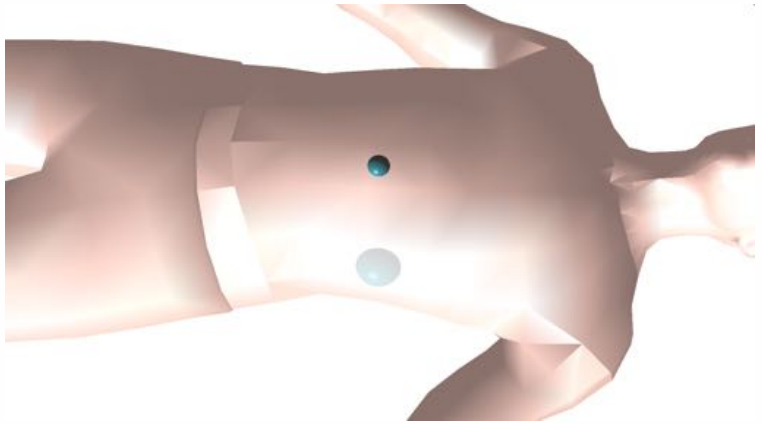


Sean Follmer, Elliot Hawkes, Margaret Koehler, Nathan Usevitch

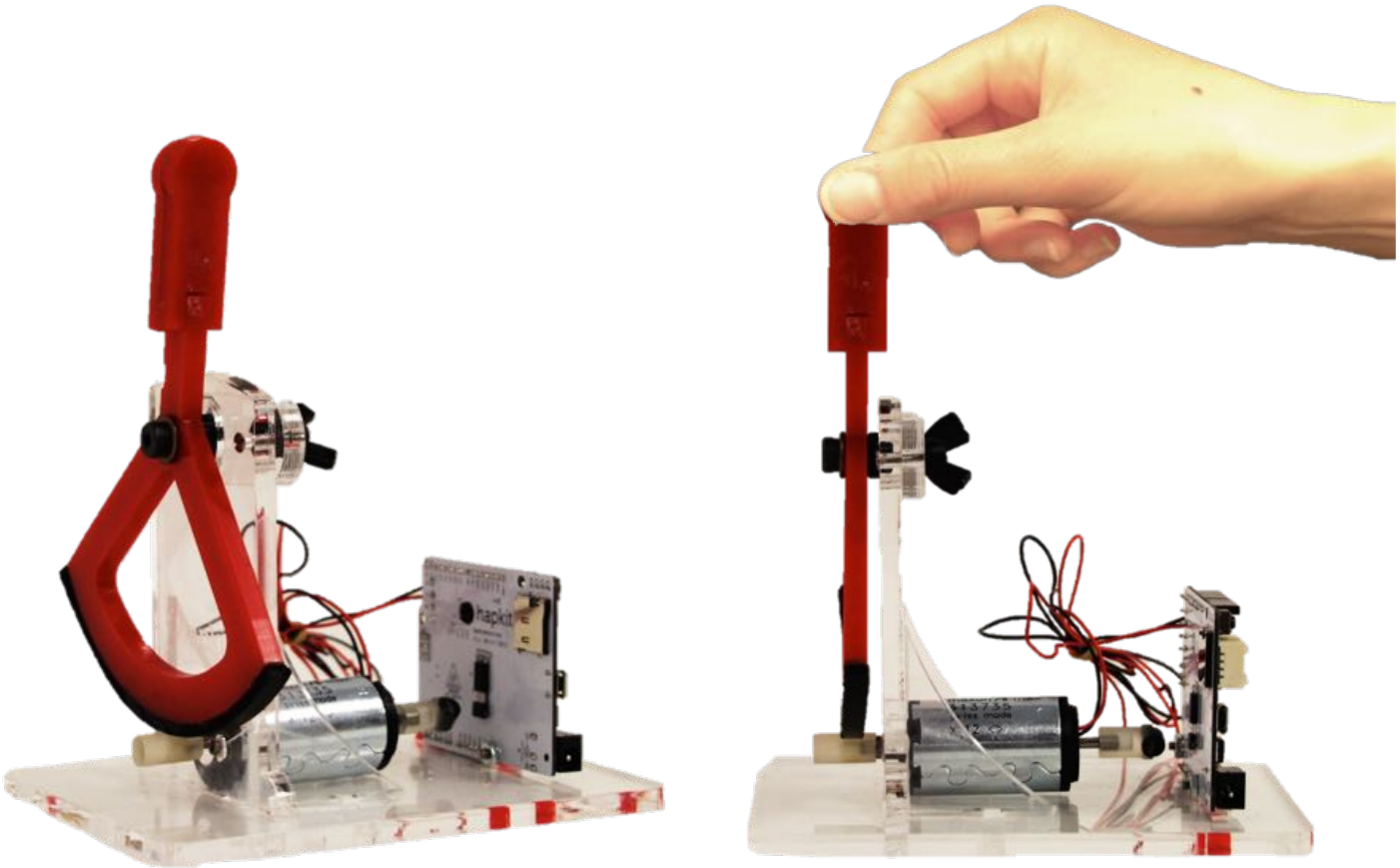
Encountered-Type Medical Simulator





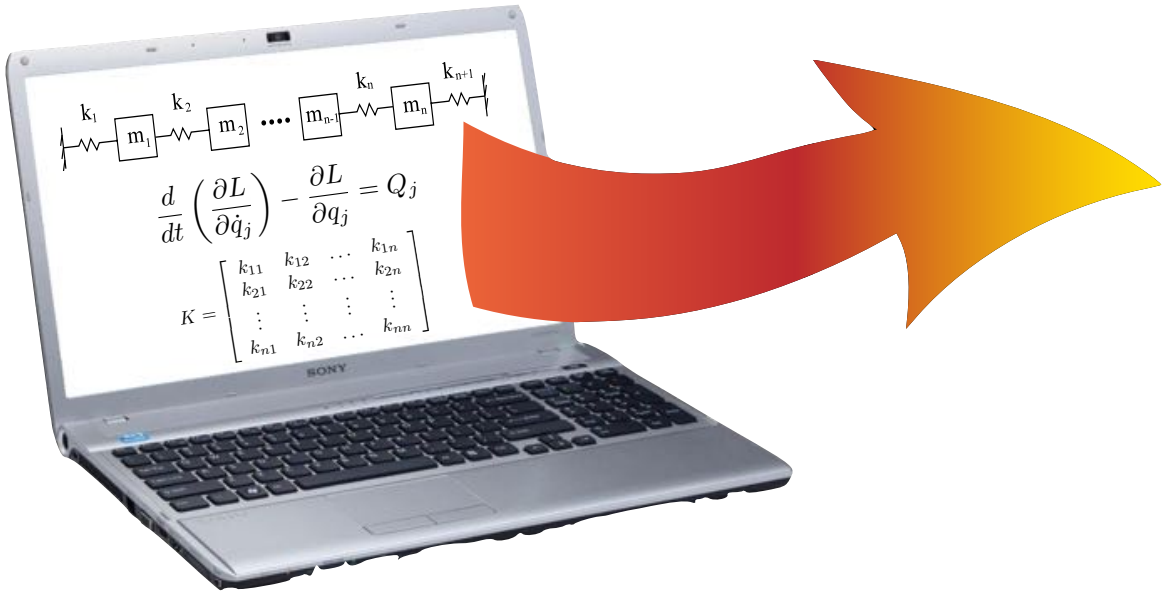


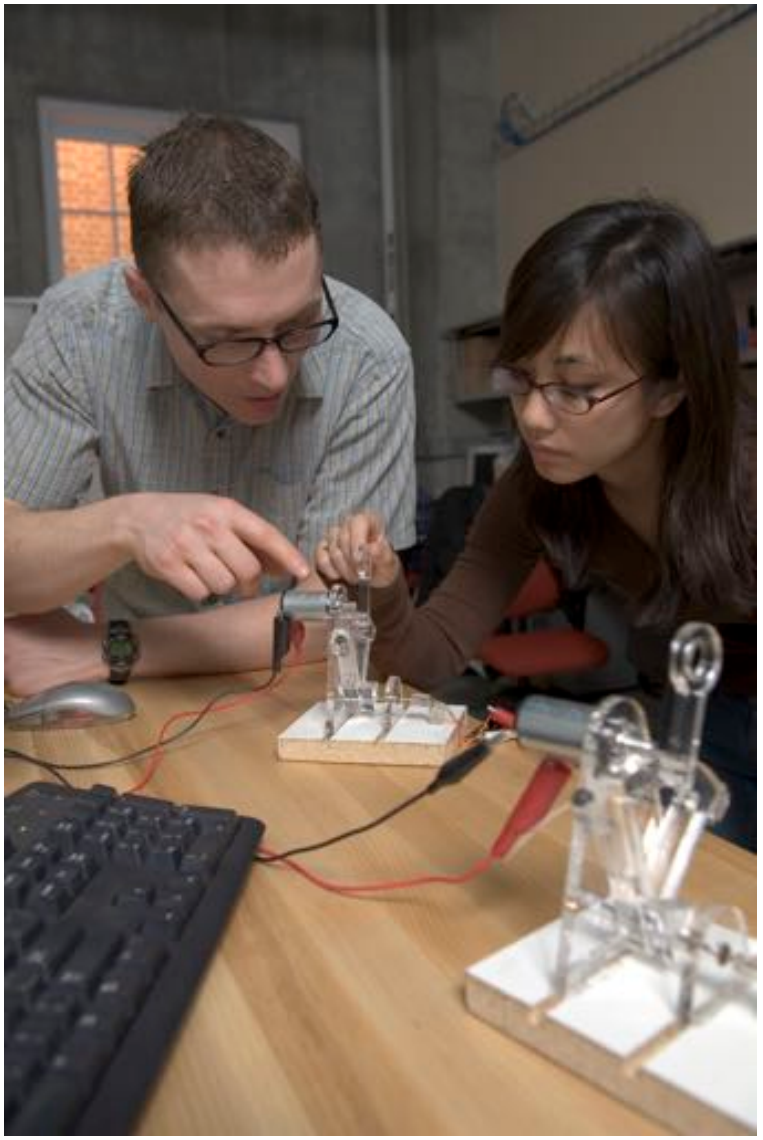
Haptics for Education



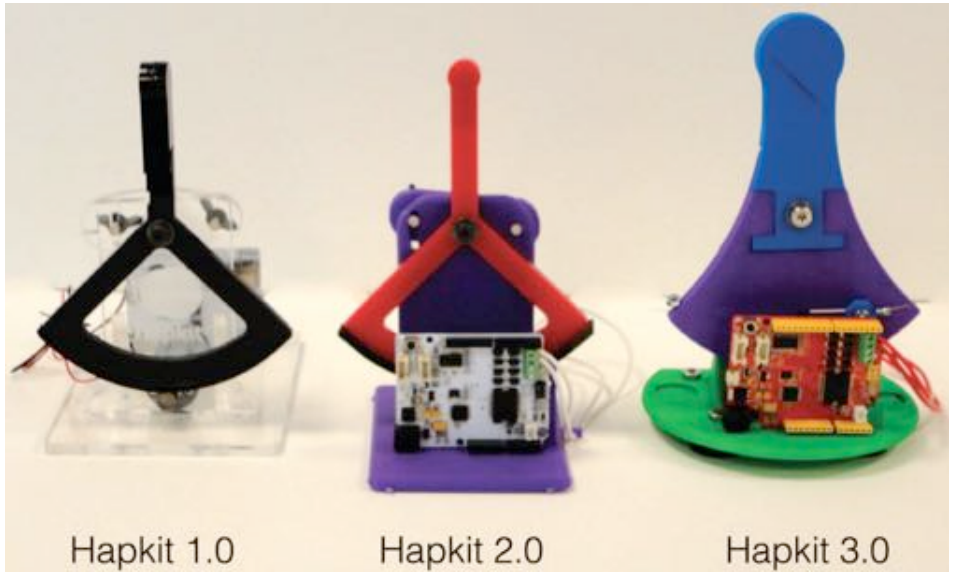
Sequoia High School
Redwood City, CA

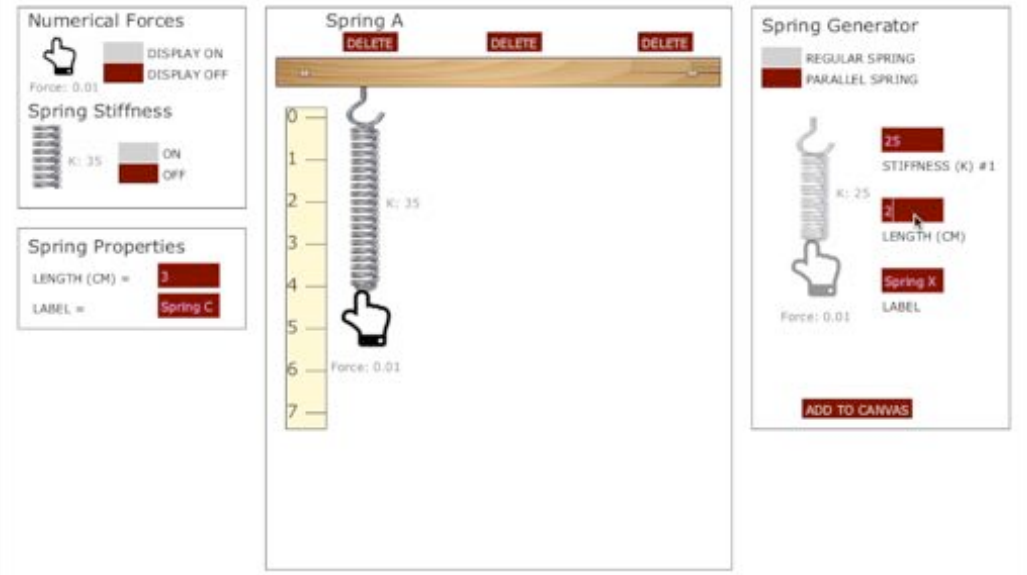
Warm Springs Elementary School
Fremont, CA


k1
m1
k2
m2
mn-1
kn
mn
kn+1
$\frac{d}{dt}\left(\frac{\partial L}{\partial \dot{q}_j}\right) - \frac{\partial L}{\partial q_j} = Q_j$
$K = \begin{bmatrix} k_{11} & k_{12} & \cdots & k_{1n} \\ k_{21} & k_{22} & \cdots & k_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ k_{n1} & k_{n2} & \cdots & k_{nn} \end{bmatrix}$
SONY



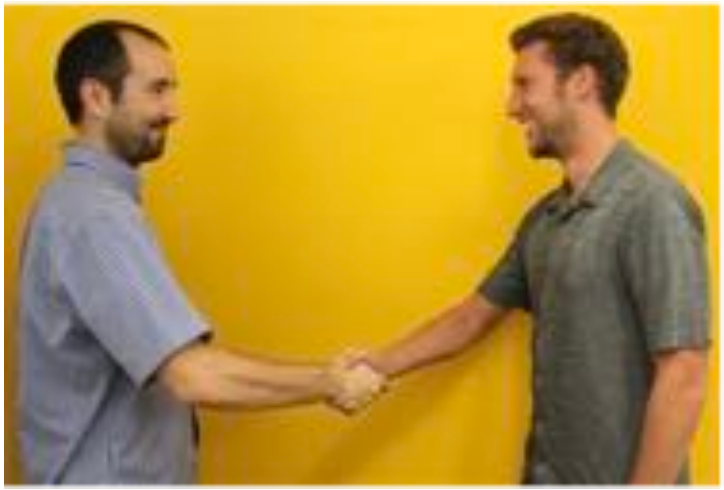
hapkit





http://hapkit.stanford.edu

Melisa Orta Martinez, Richard Davis, Tania Morimoto, Paulo Blikstein

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Thank You

This work was supported in part by:

- National Science Foundation
- National Institutes of Health
- Department of Defense
- Oculus VR
- Facebook
- MediaX

http://charm.stanford.edu