1891

ME 23N: Soft Robots for Humanity
Autumn 2019

Week 2:
Localized Compliance and Shape Memory Alloys

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Motivation for Soft Robots

The development of robotics as a field has been heavily influenced by industry, especially automation, manufacturing, transportation, and aerospace.

Building upon technologies, techniques, materials, mechanisms, and design strategies developed in areas such as these, the robotic platforms that developed aspired to ideals such as **strength, high precision and speed**, and, partly as a consequence, rigid links and joints, and thus **high stiffness**.

Material courtesy Yon Visell, UCSB

Conventional (non-soft robots)

Advantages

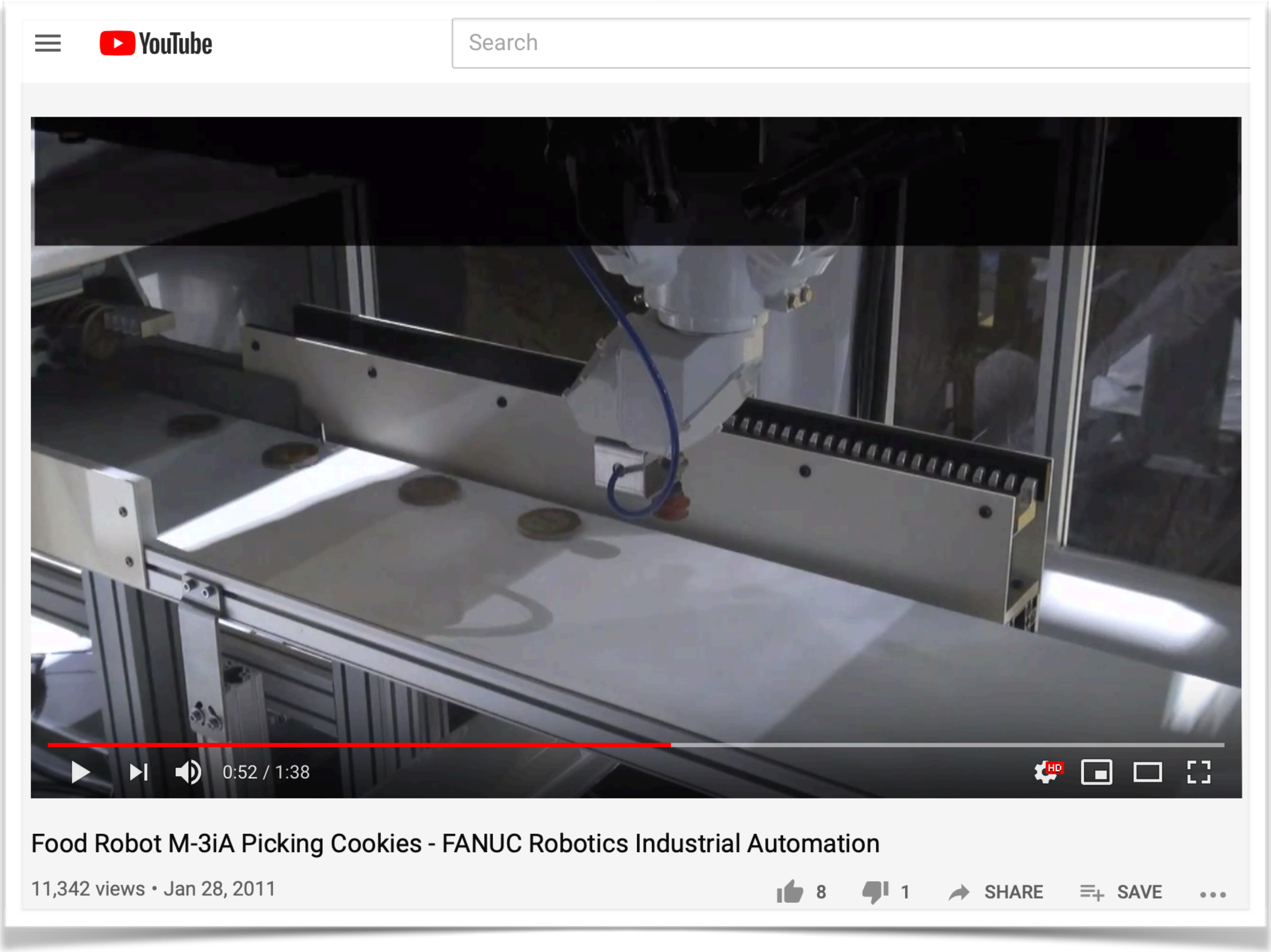
+ Stiffness ➜ High speed
+ Precise motion
+ Predictable
+ High load capacity
+ Mature technologies

Disadvantages

- Rigid links, Hard Materials ➜ Dangerous ➜ Safety ➜ Segregated
- Can be mechanically complex
- Lack of compliance ➜ Limited adaptability ➜ Difficult to interact with uncertain environments
- Can be inappropriate for handling delicate or soft materials

Material courtesy Yon Visell, UCSB

Example: FANUC Robot picking and placing cookies



Food Robot M-3iA Picking Cookies - FANUC Robotics Industrial Automation

11,342 views • Jan 28, 2011

https://www.youtube.com/watch?v=vjdfjO7ILmw

Soft Robotics is an emerging field addressing the design of highly flexible robots, animated structures, or other embodied systems constructed from soft materials, and often having analogies to biological organisms.

Materials

- Flexible (plastics, metal films/foils, fabrics, …)
- Soft/Stretchable (elastomers / polymers, …)
- Fluids (gasses, liquids)

Inspiration from Biology

Material courtesy Yon Visell, UCSB

Inspiration from Biology

Astoundingly capable biological systems

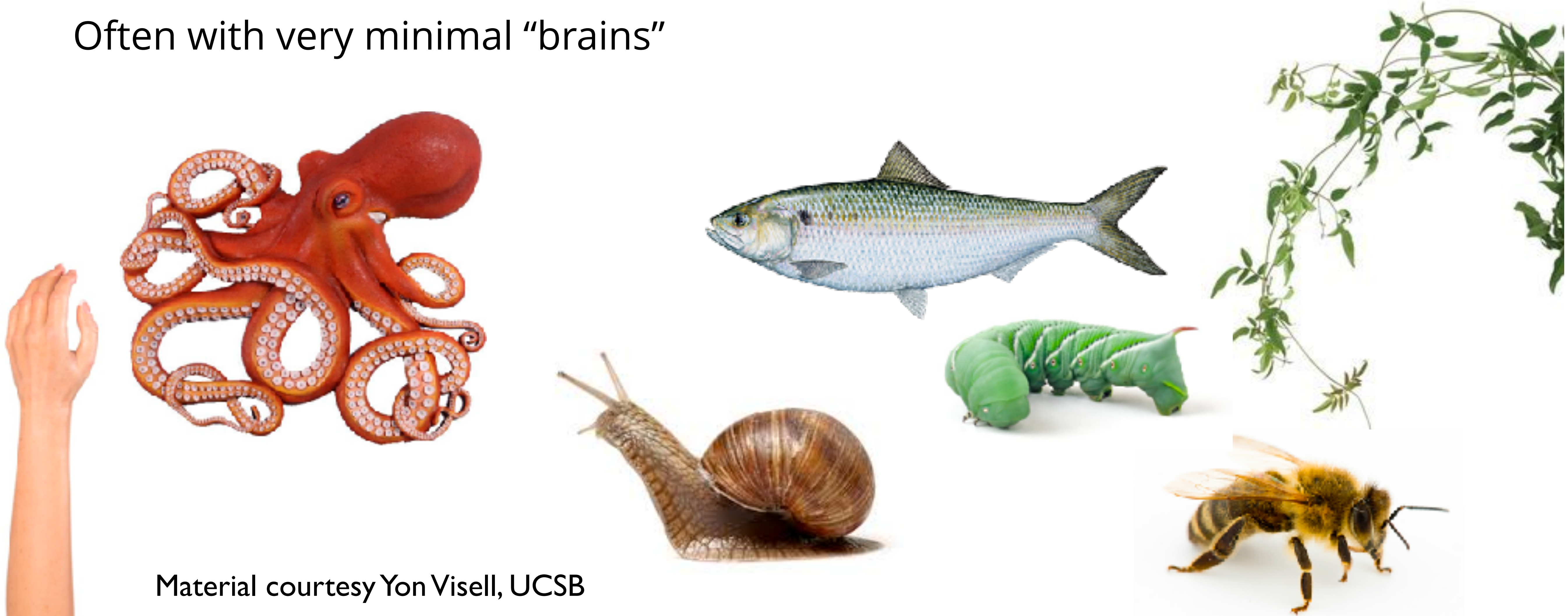
Simple, effective, reduced complexity, high dexterity

Morphological intelligence

Operate in highly challenging, uncertain environments…

Exploiting **softness, body compliance, dynamics**…

Often with very minimal “brains”



Material courtesy Yon Visell, UCSB

Example: Octopus

https://www.youtube.com/watch?v=AG6JebW63f4

Example: Dead fish

Dead trout in flowing water

2,129 views • Jun 27, 2012

https://www.youtube.com/watch?v=_ZBWnhzYvts

Features and Challenges

Design and Fabrication

Unconventional materials require different techniques

Design and fabrication are major research areas
Room for innovation

Control

Soft robotic systems are continuum mechanical systems
Challenging to control and predict
However, softness can allow these systems to better adapt

Tasks and Applications

Movement / Locomotion / Shape Change Grasping, Manipulation

Applications

Manufacturing, Inspection, Search and Rescue, and many more...

Material courtesy Yon Visell, UCSB

Mobility

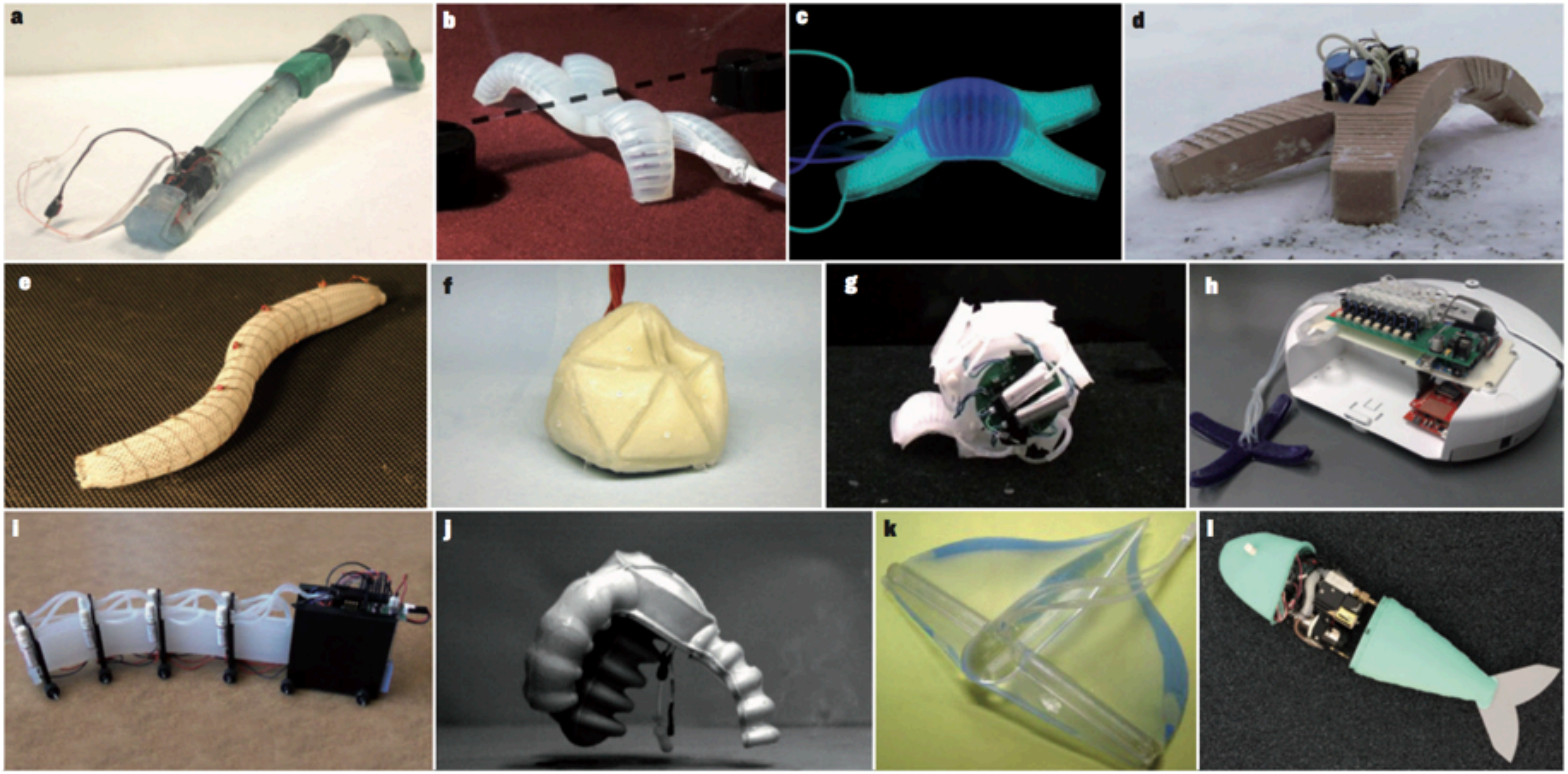


Figure 1 | Mobile soft-robotic systems inspired by a range of biological systems. **a,** Caterpillar-inspired locomotion[20]. **b,** A multi-gait quadruped[29]. **c,** Active camouflage[35]. **d,** Walking in hazardous environments[10]. **e,** Worm-inspired locomotion[88]. **f,** Particle-jamming-based actuation[42]. **g,** Rolling powered by a pneumatic battery[28]. **h,** A hybrid hard–soft robot[89]. **i,** Snake-inspired locomotion[8]. **j,** Jumping powered by internal combustion[58]. **k,** Manta-ray inspired locomotion[100]. **l,** An autonomous fish[11].

Grasping

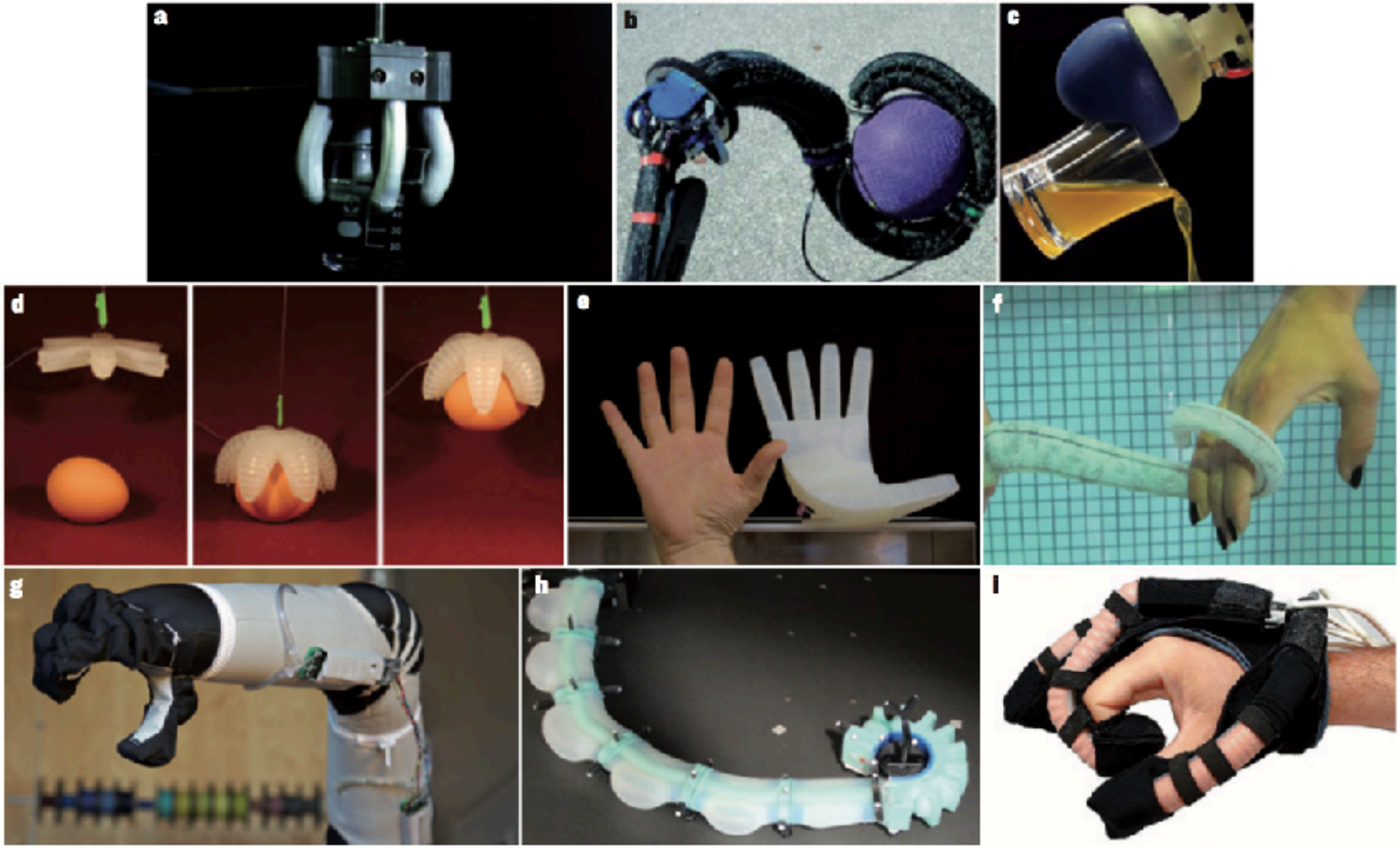


Figure 3 | Grasping and manipulation, which are canonical challenges in robotics, can be greatly simplified with soft robotics. Examples of experimental soft-robotic manipulation systems demonstrating microactuation[27] (**a**), soft-continuum manipulation[19] (**b**), grasping with particle jamming[44] (**c**), simple gripper fabrication by soft lithography[33] (**d**), underactuated dextrous grasping[13] (**e**), octopus-inspired manipulation[24] (**f**), inflatable robotic manipulators[91] (**g**), feedback control of a multisegmented arm[30] (**h**) and a soft glove for rehabilitation[32] (**i**).

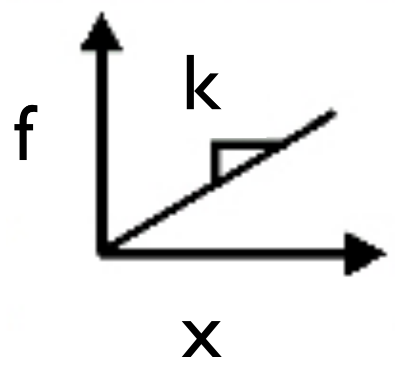
Suggested readings

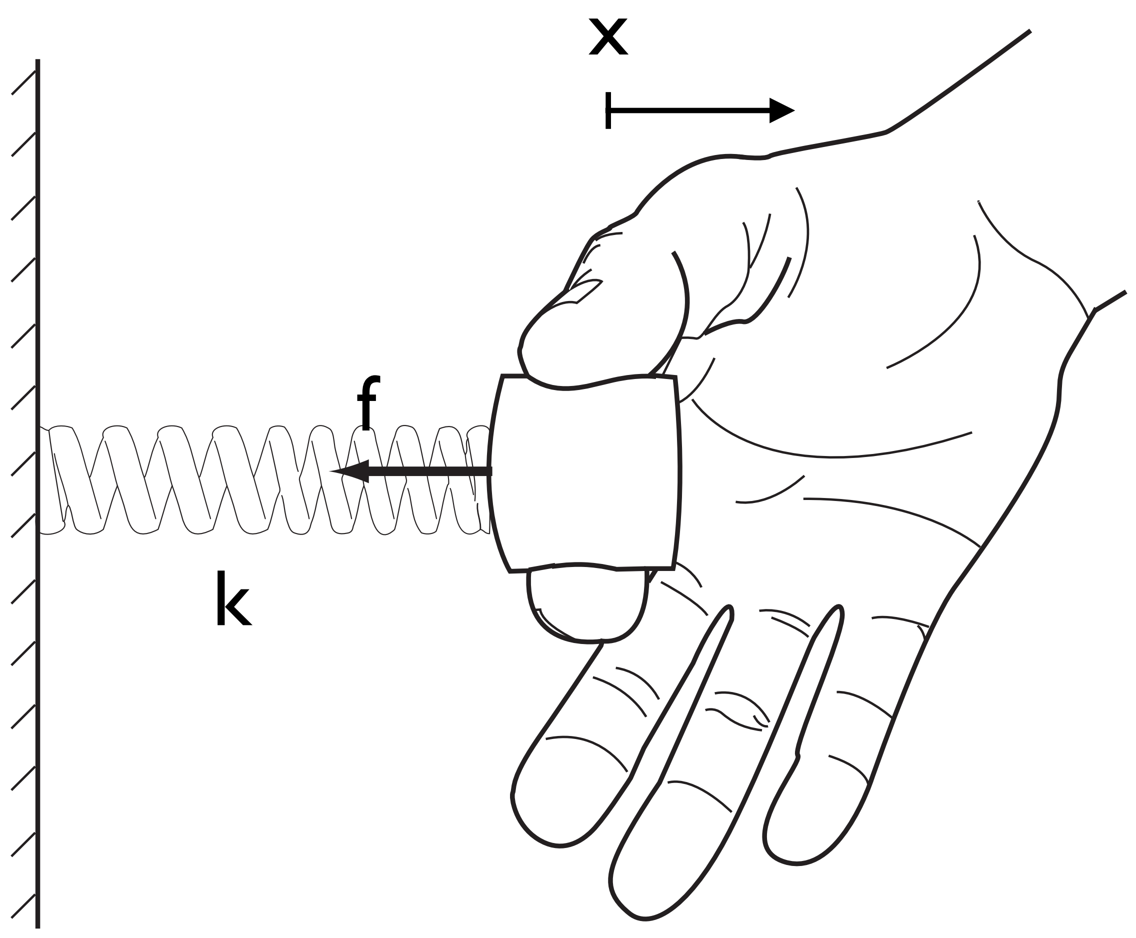
- C. Laschi, B. Mazzolai, M. Cianchetti, Soft robotics: Technologies and systems pushing the boundaries of robot abilities. Science Robotics, 2016. https://robotics.sciencemag.org/content/1/1/eaah3690
- D. Rus, M. T. Tolley, Design, fabrication, and control of soft robots. Nature, 2015. https://www.nature.com/articles/nature14543
- C. Majidi, Soft Robotics: A Perspective: Current Trends and Prospects for the Future. Soft Robotics, 2013. https://www.liebertpub.com/doi/10.1089/soro.2013.0001

Localized Compliance

Linear Stiffness/Compliance

$$f = kx$$





f is the force

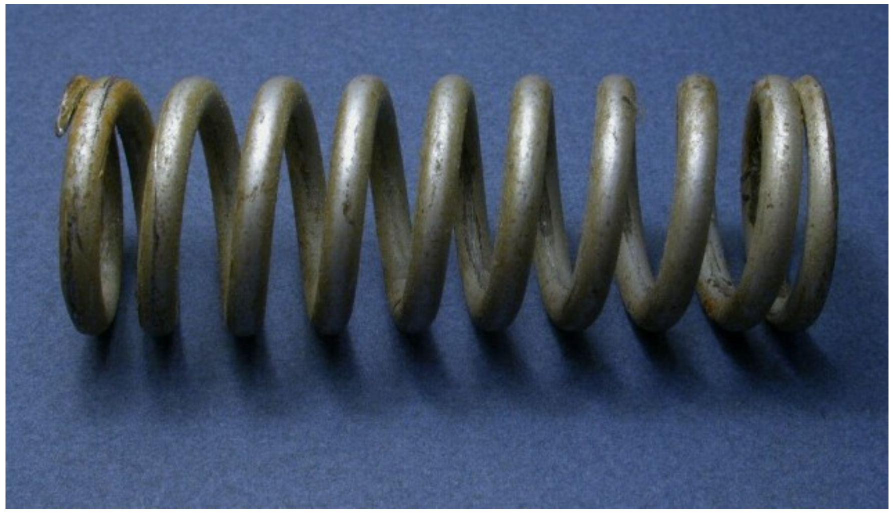
k is the stiffness
(inverse of k is compliance)

x is the deflection of the spring
(x = 0 at the equilibrium point
of the spring)

Springs

tension spring

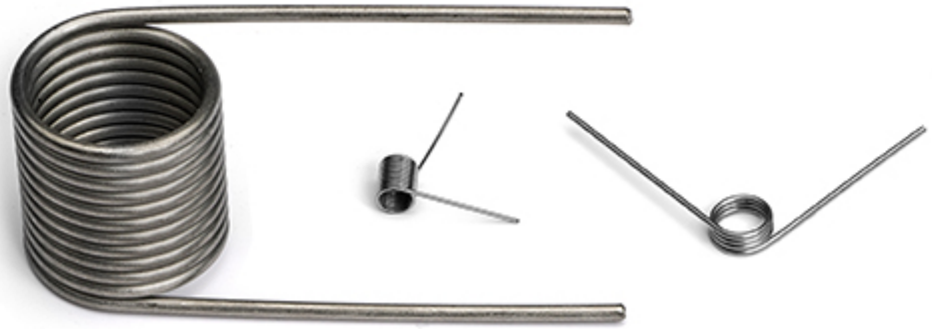
compression spring



rubber band

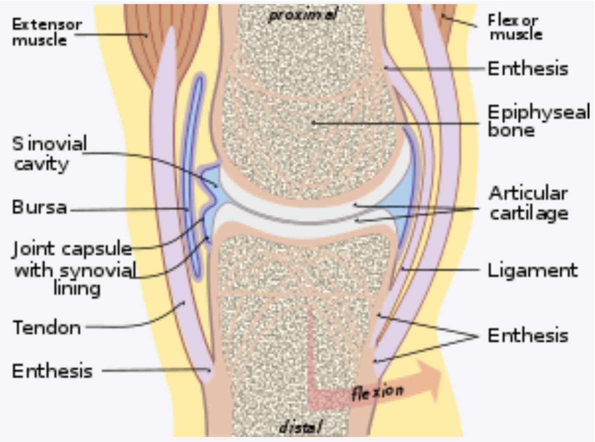
leaf spring

torsion spring



Rotary joints
(ultimate compliance = no spring!)

biological joints

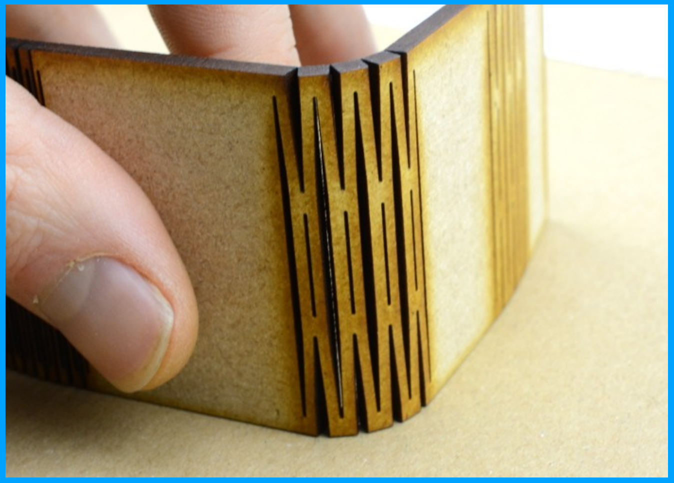


hinge

bearing

universal joint

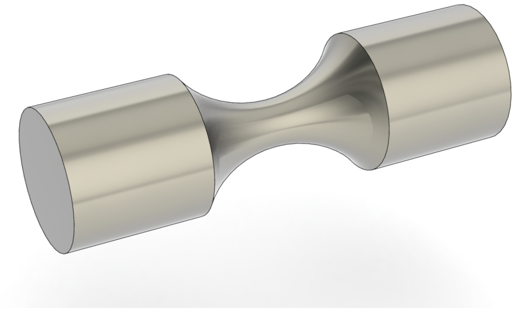
“living hinges”



Flexure

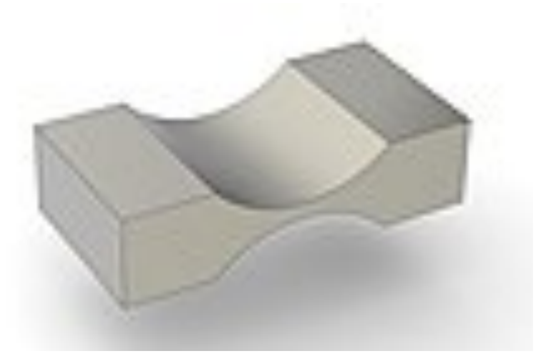
A **flexure** is a flexible element (or combination of elements) engineered to be compliant in specific degrees of freedom.

pin flexure



blade flexure

notch flexure



What material(s) can you use to create a flexure?

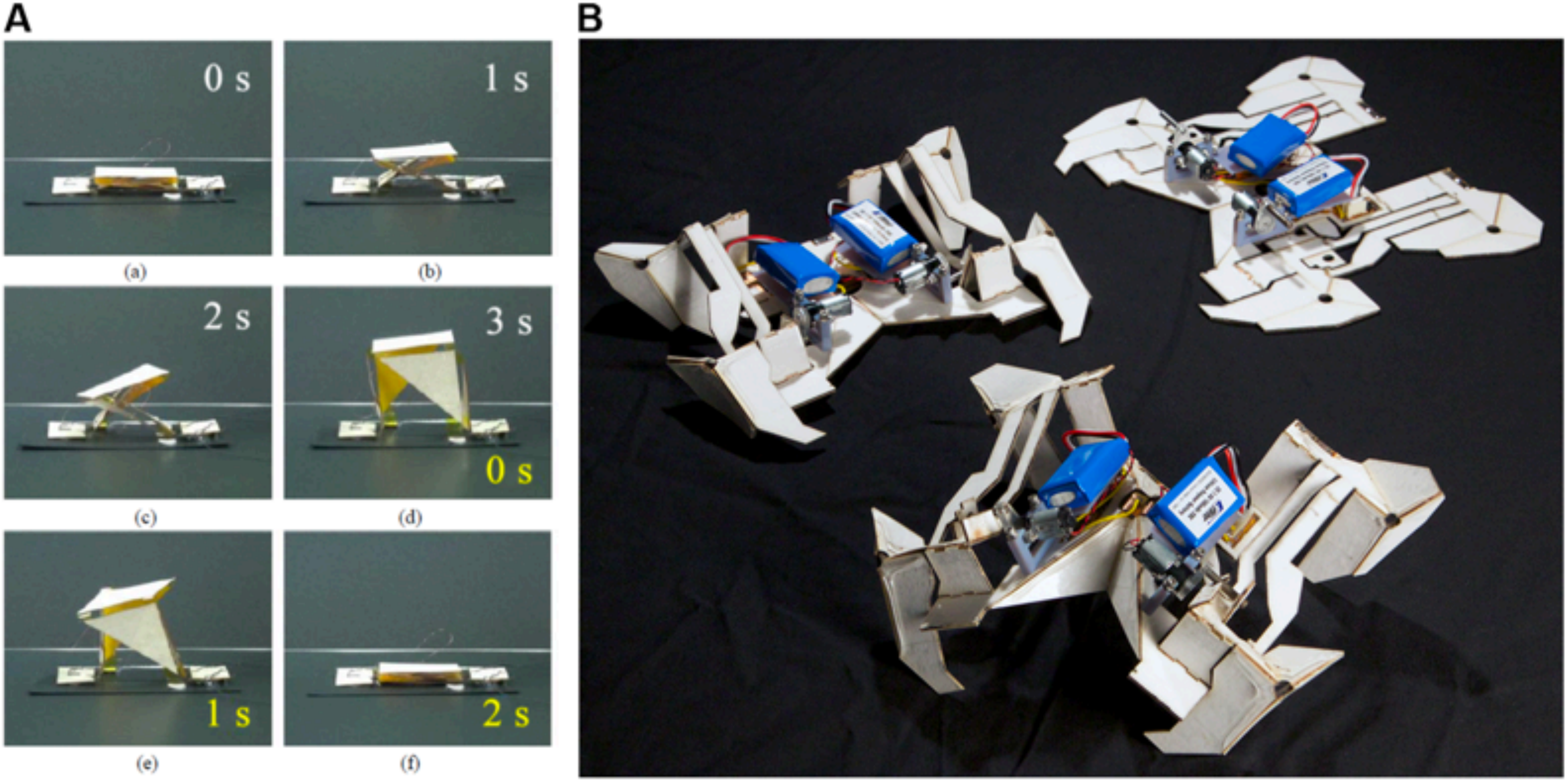


Fig. 6. Origami robots, with the ability of folding and unfolding, changing their shape in response to external stimuli. (**A**) Simple cubic building blocks based on SMA that can unfold in 3 s and fold again in 2 s (*78*); (**B**) a planar sheet of paper self-folding into a complex 3D shape thanks to embedded shape memory composites (*79*). [Credits: self-folding origami robot, K.-J. Cho; self-folding machines, Wyss Institute at Harvard University].

Shape Memory Alloys

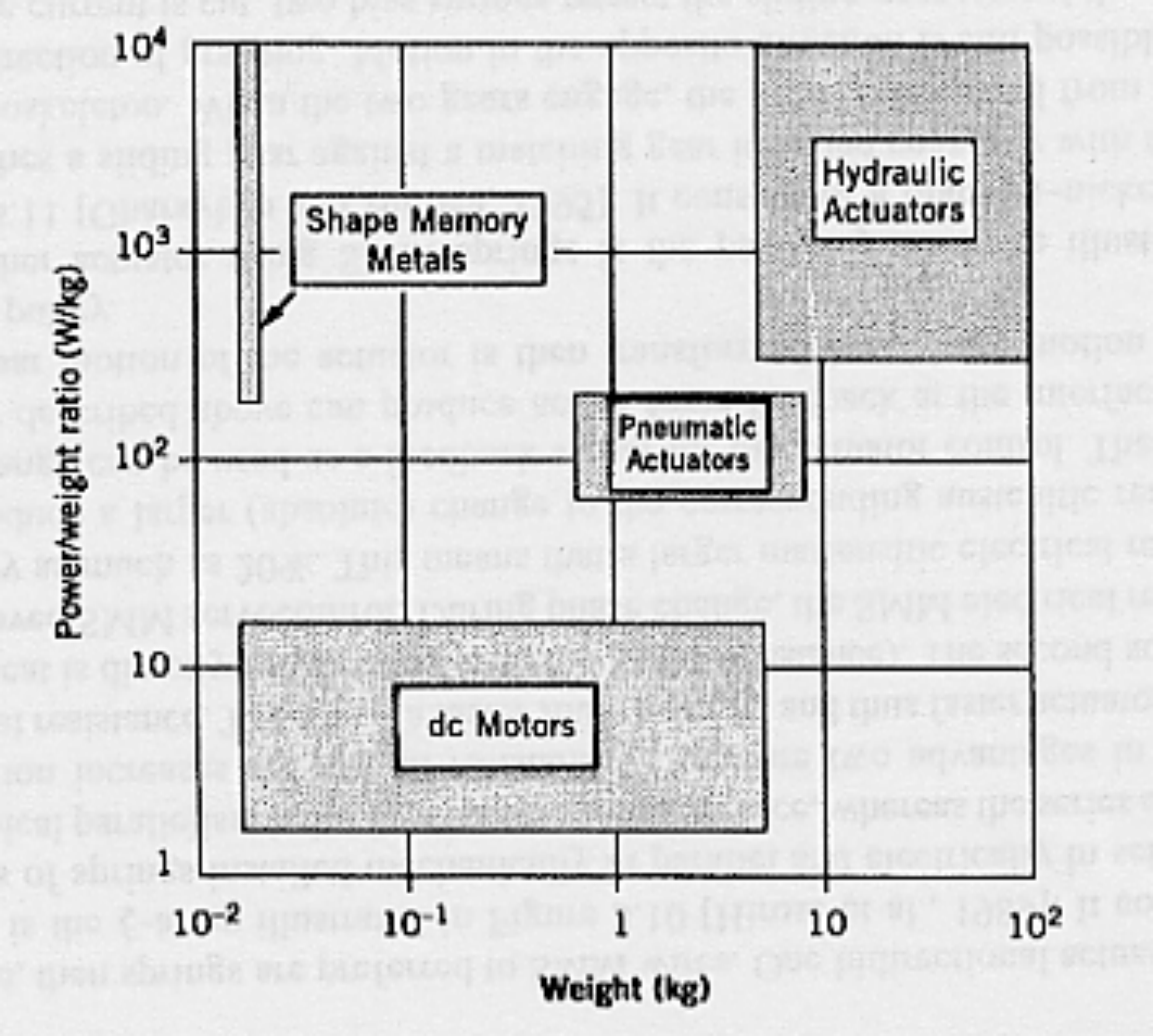
Actuators

An **actuator** is a component of a machine that is responsible for moving and controlling a mechanism or system, for example by opening a valve.

In simple terms, it is a “mover".

An actuator requires a control signal and a source of energy.

Choosing an Actuator



Burdea

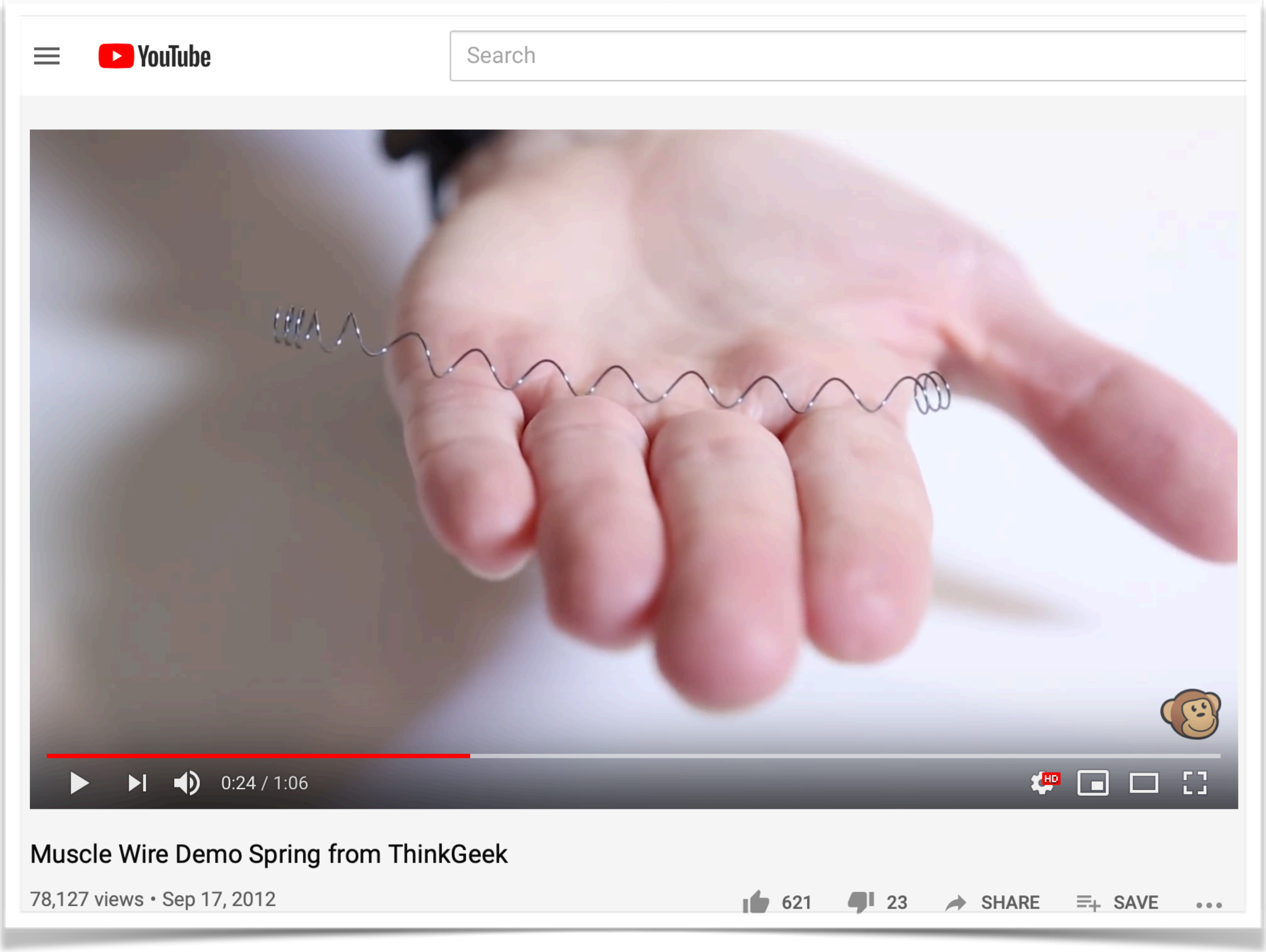
Shape Memory Alloys

May also be called **memory metal**, **memory alloy**, **smart metal**, **smart alloy**, or **muscle wire**

Two main properties:

- Can be deformed when cold but returns to its pre-deformed ("remembered") shape when heated *[this is what we will use in lab 1]*
- Superelasticity/pseudoelasticity *[this is how we make steerable needles]*

Example: Spiral Configuration



Muscle Wire Demo Spring from ThinkGeek

78,127 views • Sep 17, 2012

https://www.youtube.com/watch?v=Hs2aHC3L4Ik

Shape Memory Alloys

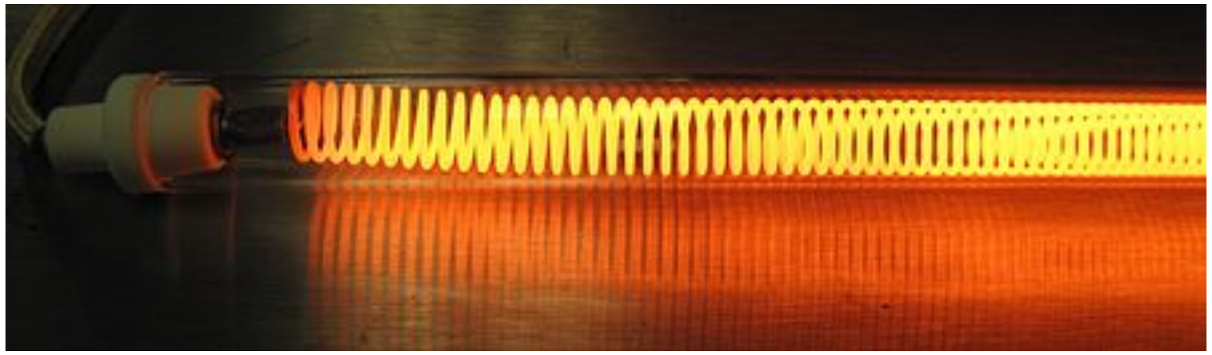
- Made up of equal parts **nickel** and **titanium**
- Developed by the United States Naval Ordnance Lab
- Because it is 50% titanium, this wire is much stronger than your average strand of wire.
- The reason Nitinol is able to expand and contract is because of its **combination of crystal structures** from the nickel and titanium metals. They react differently in high and low temperatures, making the wire soft and flexible when cool, yet firm and stiff when heated.

Shape Memory Alloys

- When at **room temperature**, Nitinol can be bent into various shapes.
- **Apply heat**, and the atoms arrange themselves into the most compact and tight fitted pattern possible, resulting in the **contraction of shape**.
- This crystal transformation is **fully reversible**. Once the temperature is lowered, it returns to, or “remembers,” its original shape. This cycle can be repeated millions of times.

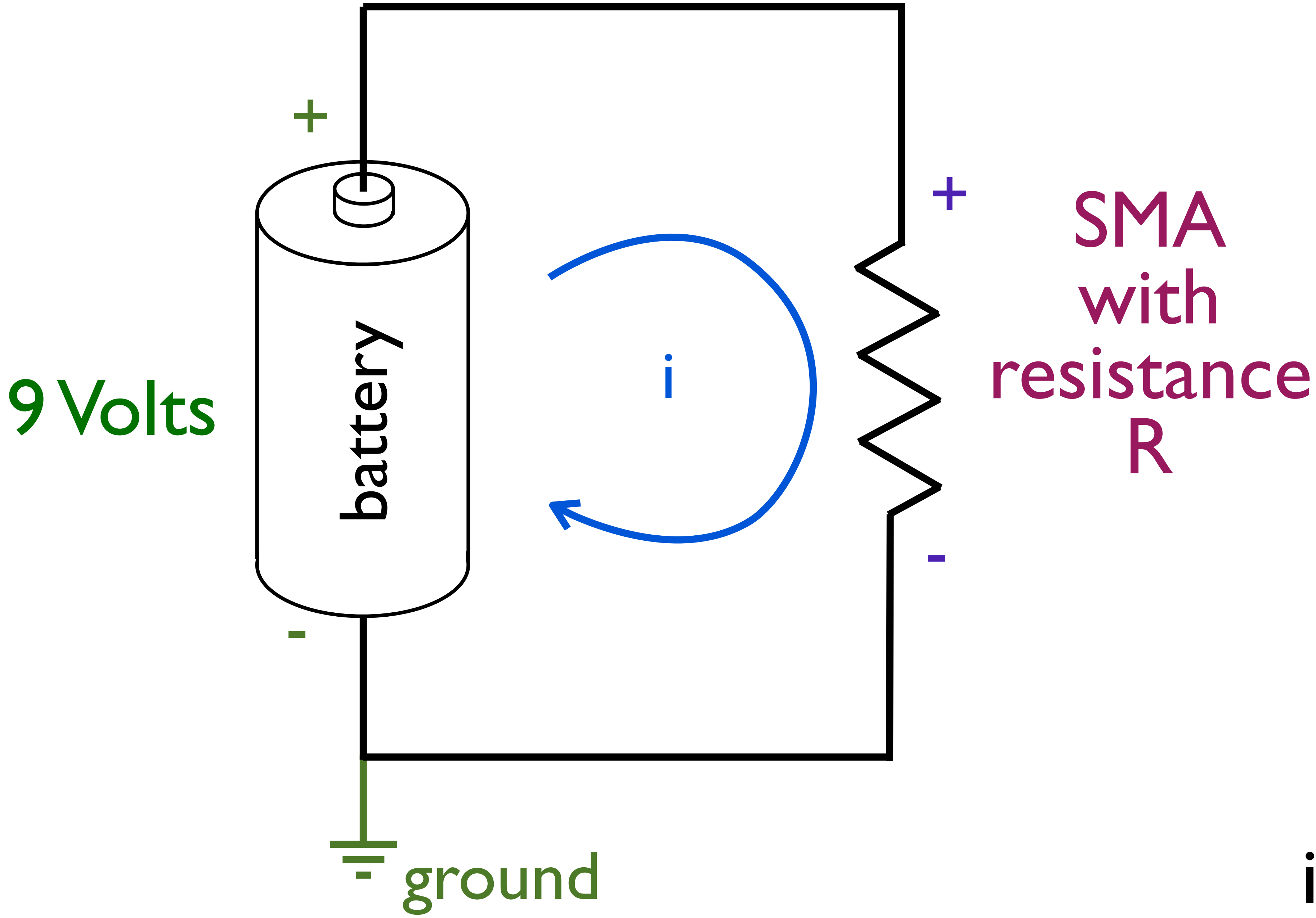
How do we heat it?

- **Joule heating**, also known as Ohmic heating and resistive heating, is the process by which the passage of an electric current through a conductor produces heat.



- Caused by interactions between electrons and the body of the conductor.

- A voltage difference between two points on a conductor creates an electric field that accelerates charge carriers in the direction of the electric field, giving them kinetic energy. When the charged particles collide with ions in the conductor, the particles are scattered; their direction of motion becomes random rather than aligned with the electric field, which constitutes thermal motion. Thus, energy from the electrical field is converted into thermal energy.



Ohm's Law:

$V = iR$

ideal power:

$P = iV = i^2R = V^2/R$

- the battery is a 9V source
- current flows from high voltage to low voltage
- the current / induced voltage drop across the SMA results in Joule heating

To Do

- Take over a lab bench with your partner (see next slide).

- Read the lab handout first, including the questions!

- Work on the lab for the rest of today and Thursday.

- Answer the questions in your lab notebook (clearly label it with the date and "Lab 1"). Turn in the lab notebook by the end of class on Thursday, or let us know if you need more time/help.

Groups of two for Lab 1

1	Leena	Nadin
2	Caroline	Youngju
3	Brian	Angelo
4	Tomas	Alana
5	Sochima	Huy
6	Cherié	Emma
7	Nick	Josue
8	Senkai	Ellie