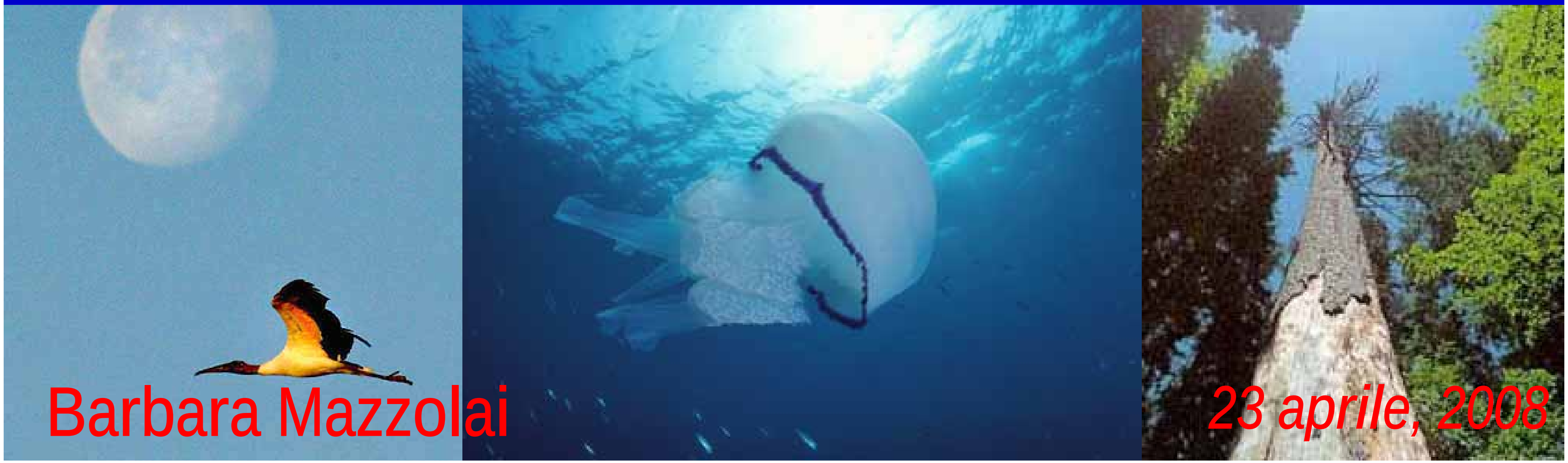
Corso di Percezione Robotica (PRo)

Prof.ssa Cecilia Laschi

Fondamenti di Robotica Biomimetica



Barbara Mazzolai

23 aprile, 2008

Contenuti del modulo

I Lezione:

- Introduzione alla biorobotica;
- Classificazione degli organismi viventi;
- Fondamenti della zoologia;
- 1° caso studio: robot bio-ispirati ai molluschi

II Lezione:

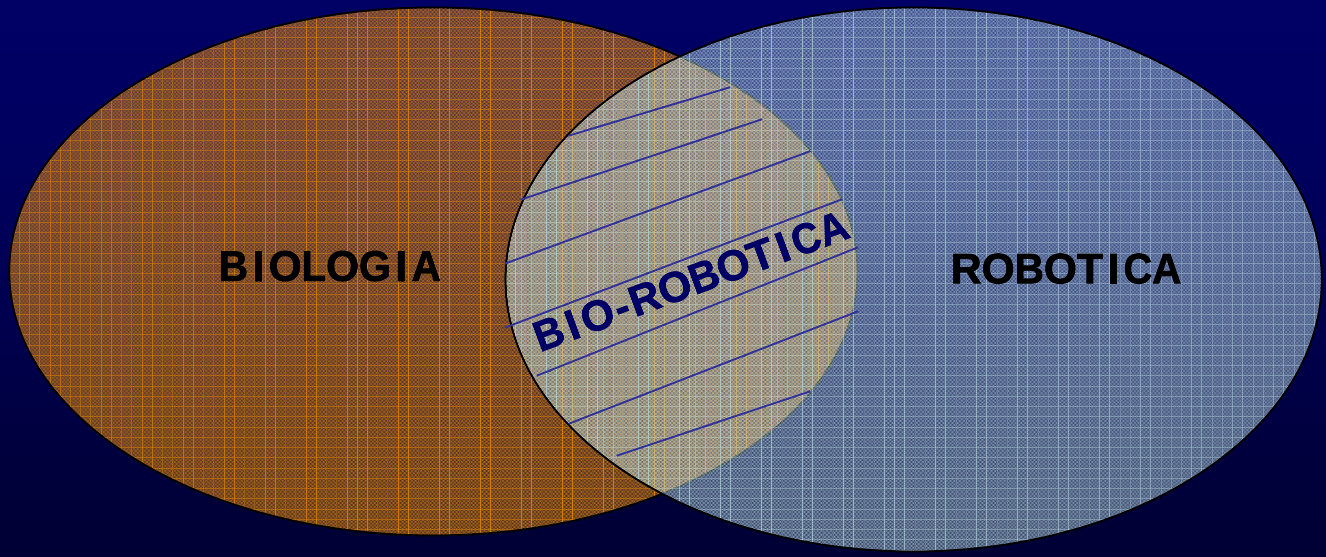
- Artropodi
- 2° caso studio: robot bio-ispirati agli artropodi

I PARTE

INTRODUZIONE ALLA BIOROBOTICA

Introduzione

Biorobotica può essere definita come l'intersezione tra la biologia e la robotica (Webb, B., 2001)



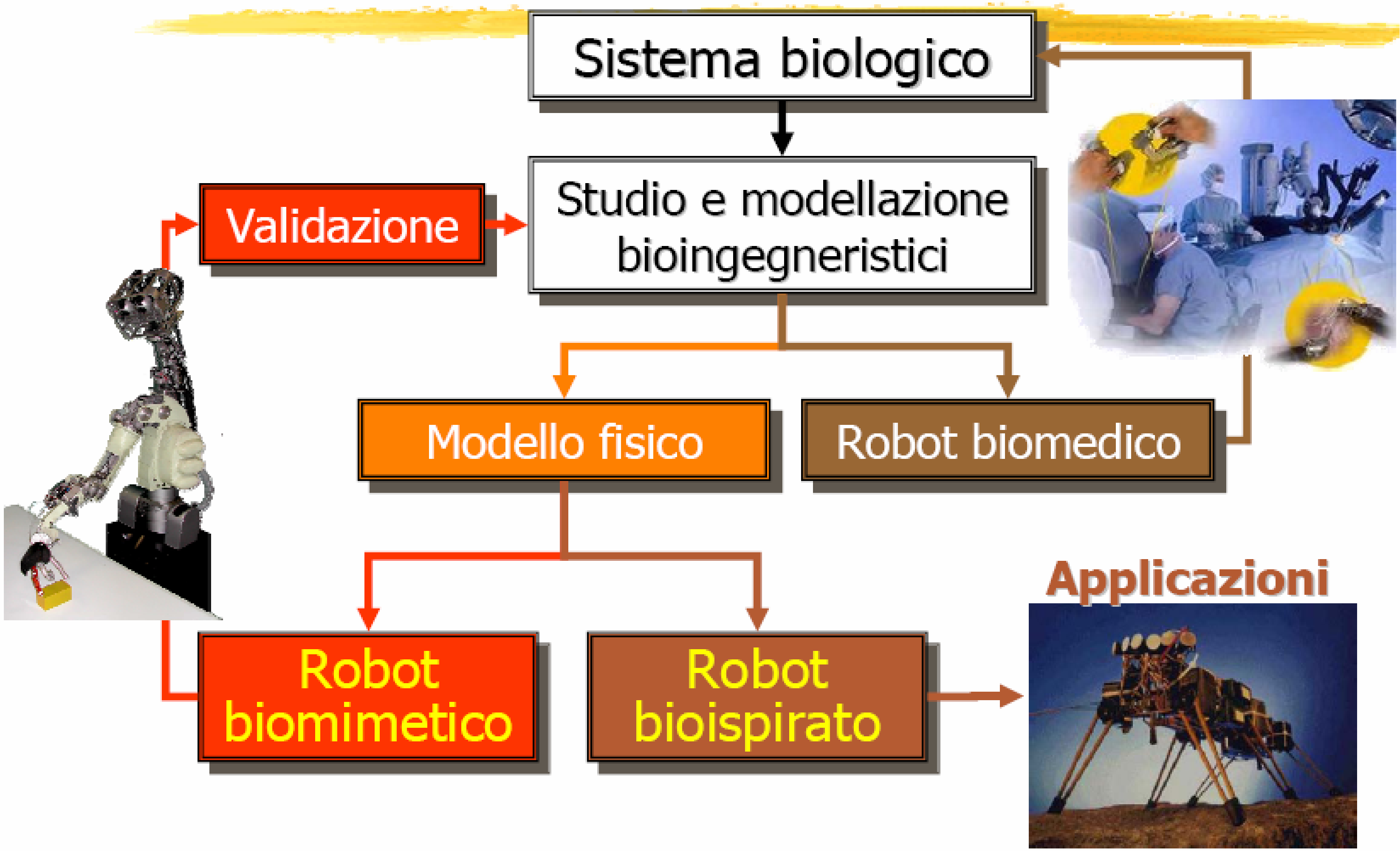
Obiettivi della Robotica Bioispirata

Analizzare e capire come funzionano i sistemi biologici e prendere **ispirazione** da questa conoscenza per progettare nuovi e migliori sistemi robotici

Obiettivi della Robotica Biomimetica

- Analizzare e studiare come funzionano i sistemi biologici e usare questi modelli per progettare nuovi e migliori sistemi robotici che **imitano** le funzionalità della loro controparte biologica
- Sviluppare piattaforme fisiche **equivalenti** ai sistemi biologici, al fine di testare sperimentalmente "modelli" di sistemi viventi e i loro principi funzionali

Robotica bio-ispirata



I robot e il modello biologico

Modelli biologici per la progettazione e realizzazione di robot bioispirati

Interfaccia tra Biologia e Robotica

Robot come piattaforme fisiche per validare modelli biologici e spiegare il comportamento dell'animale

Cosa significa essere biologicamente ispirato?

Sono possibili molti **livelli di bioispirazione**, da una vaga somiglianza ad una stretta emulazione.

Nel caso della locomozione di robot ispirati ad insetti

- **Semplici esempi** di ispirazione biologica (ad es. osservare che gli animali usano le zampe anziché le ruote, o che l'uso di sei zampe nell'insetto fornisce maggiore stabilità);
- **Emulare**, in ogni dettaglio, una particolare specie di insetto;
- Studiare il numero e la configurazione dei **gradi di libertà della zampa** utilizzati dall'insetto per attraversare terreni accidentati e, sulla base degli effetti di torsione che questi gradi di libertà esercitano, selezionare la migliore geometria del robot;
- Esaminare in dettaglio i tipi di **informazioni sensoriali** che l'insetto usa per ben adattare I movimenti delle zampe;
- Cercare di emulare le differenti **strategie comportamentali** che l'insetto usa per attraversare terreni di varia natura;
- Cercare di basare la progettazione **dei controllori del cammino** per robot su zampe sui principi architetturali e funzionali dei circuiti nervosi implicati nel controllo del cammino dell'insetto.

Biomimetica

La Biomimetica è stata applicata ad un ampio numero di settori (cibernetica, intelligenza di sciame, neuroni artificiali, reti di neuroni artificiali, robotica, ecc.)

Generalmente sono tre le aree della biologia alle quali si ispirano le soluzioni tecnologiche:

- Replicare i metodi naturali di **fabbricazione di composti chimici** prodotti dalle piante e dagli animali (e.g. soft tissues, such as muscle; rubber produced by plants -*Ficus elastica*-; etc.)

- Imitare i **meccanismi** presenti in Natura, come quelli del Velcro e "Adesivo modello Geco"

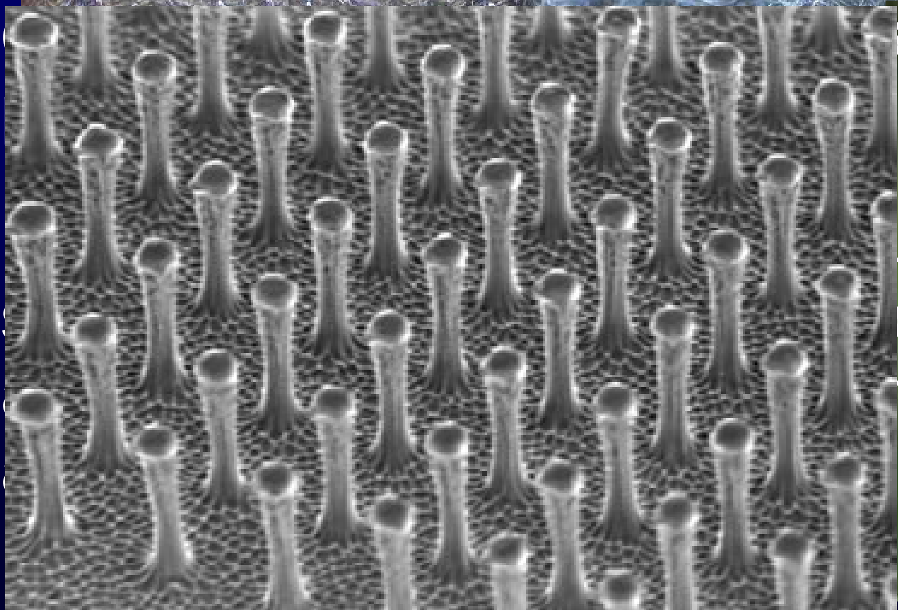
- Imitare i principi dei **comportamenti sociali** di organismi come le formiche, le api e i microorganismi.

Biomimetica

Alcuni esempi di biomimetica:

• Il Velcro è stato ideato nel 1941 da un ingegnere svizzero, George de Mestral, notando che gli uncini di una pianta (*Arctium lappa*) si attaccavano al pelo del suo cane.

• Un gruppo di ricerca (Bell La) ha scoperto che una spugna tropi to di Venere, costruisce strutture resi eriali



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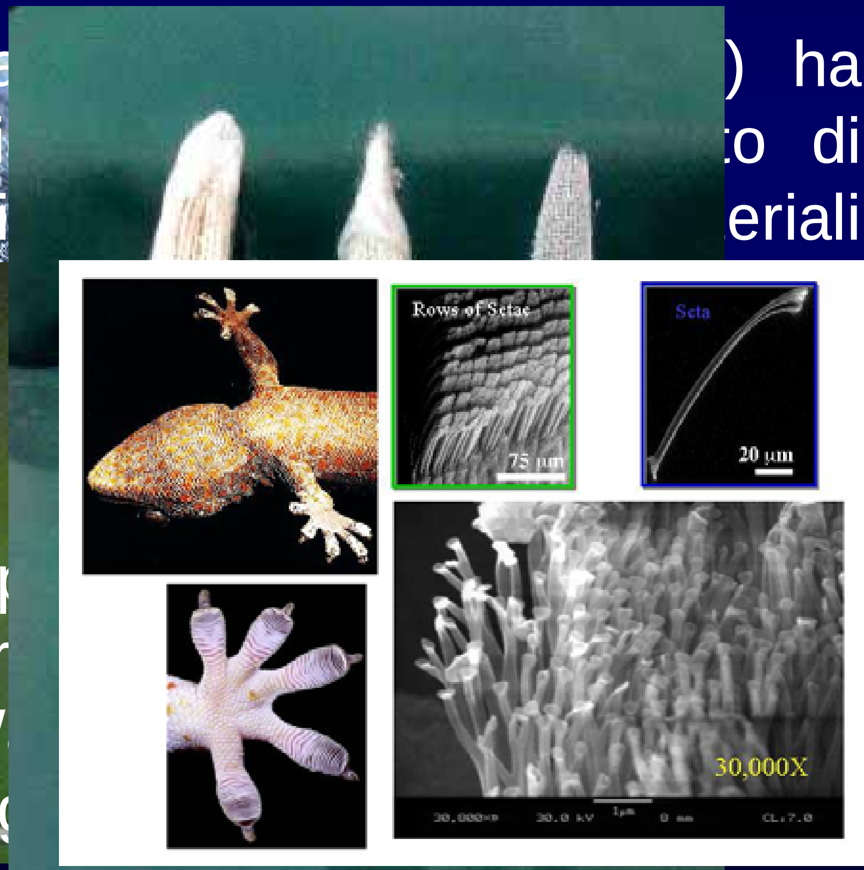
presenti sui piedi.



Biomimetica

- DaimlerChrysler sta sviluppando un nuovo modello di veicolo a basso consumo energetico ispirato alla forma del corpo del pesce scatola, un pesce che si trova comunemente nei mari tropicali. La macchina bionica offrirà un 20% di consumo di carburante in meno e una riduzione superiore all’80% di emissione di NO_2.

Biomimetica

Tuttavia..

"We think blind copying is exactly what you don't want to do," says Robert Full, a biologist at the University of Berkeley, California. "You will fail miserably, because nature is way too complex."

La selezione naturale non è Ingegneria

Attraverso l'**evoluzione**, la Natura ha "sperimentato" varie soluzioni e selezionato quelle più vantaggiose in relazione all'ambiente. Gli organismi in grado di sopravvivere **non sono necessariamente la soluzione ottimale** per le loro performance tecniche. Devono sopravvivere sufficientemente a lungo per riprodursi.

Esempi di alcuni dei più importanti risultati ingegneristici del 20° secolo

1. Electrification
2. Automobile
3. Airplane
4. Water Supply and Distribution
5. Electronics
6. Radio and Television
7. Agricultural Mechanization
8. Computers
9. Telephone
10. Air Conditioning and Refrigeration
11. Highways
12. Spacecraft
13. Internet
14. Imaging
15. Household Appliances
16. Health Technologies
17. Petroleum and Petrochemical Technologies
18. Laser and Fiber Optics
19. Nuclear Technologies
20. High-performance Materials

Evoluzione vs Ingegneria

- Engineers often have final goals, whereas biological evolution does not.
- Organisms must do a multitude of tasks, whereas in engineering executing far fewer tasks will do.
- Trade-offs are the rule, severe constraints are pervasive and global optimality rare in biological systems.
- Biological evolution works more as a tinkerer than an engineer.
- Tinkerers never really know what they will produce and use everything at their disposal to make something workable.

Biology as a model

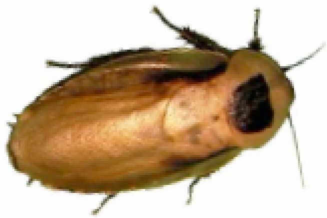
In order to harness the most from Nature's inventions it is critical **to bridge between the fields of biology and engineering.**

This bridging effort can be a key **to turning Nature's inventions into engineering capabilities, tools, and mechanisms.**

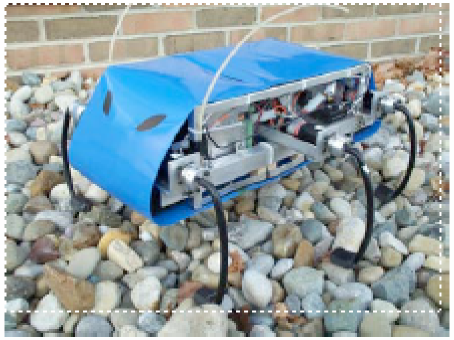
The job of the biomimeticist is to identify the system (or systems) responsible for producing the desired characteristic, to extract the key principles underlying their biological function, and then to translate them to a technological solution. Consequently, one cannot simply copy Nature, but rather carefully choose Nature's behaviour of focus, and extract the underlying principle at a level of description that is actually possible to implement.

Biological Inspiration

Biology



Passive, Dynamic,
Self-stabilization



RHex

UPenn, Boston Dynamics, Berkeley

Engineering

Electric Motor

Use Principles and Analogies from Biology when Advantageous. Integrate with Best Human Engineering

II PARTE

CLASSIFICAZIONE DEGLI ORGANISMI VIVENTI

Alcune definizioni

Nomenclatura

Tassonomia: un metodo sistematico di classificazione degli esseri viventi.

Classificazione: classificazione degli organismi in taxa (sing. taxon) basata sul grado di somiglianza correlata al grado evolutivo (filogenetica).

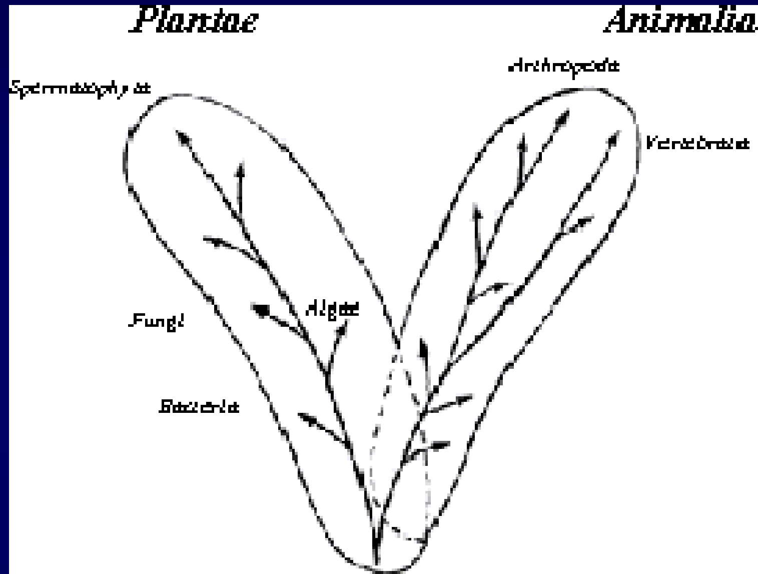
Sistematica: scienza interessata alla classificazione e allo studio degli esseri viventi in relazione ai legami naturali.

A bit of history

Aristotle’s classification of elements

Aristotle

(384-322 a.C.)



The **Animalia Kingdom** included heterotrophic organisms, endowed with movement; the **Plantae Kingdom** involved autotrophic organisms, fixed, able to perform photosynthesis.

The classification of living organisms

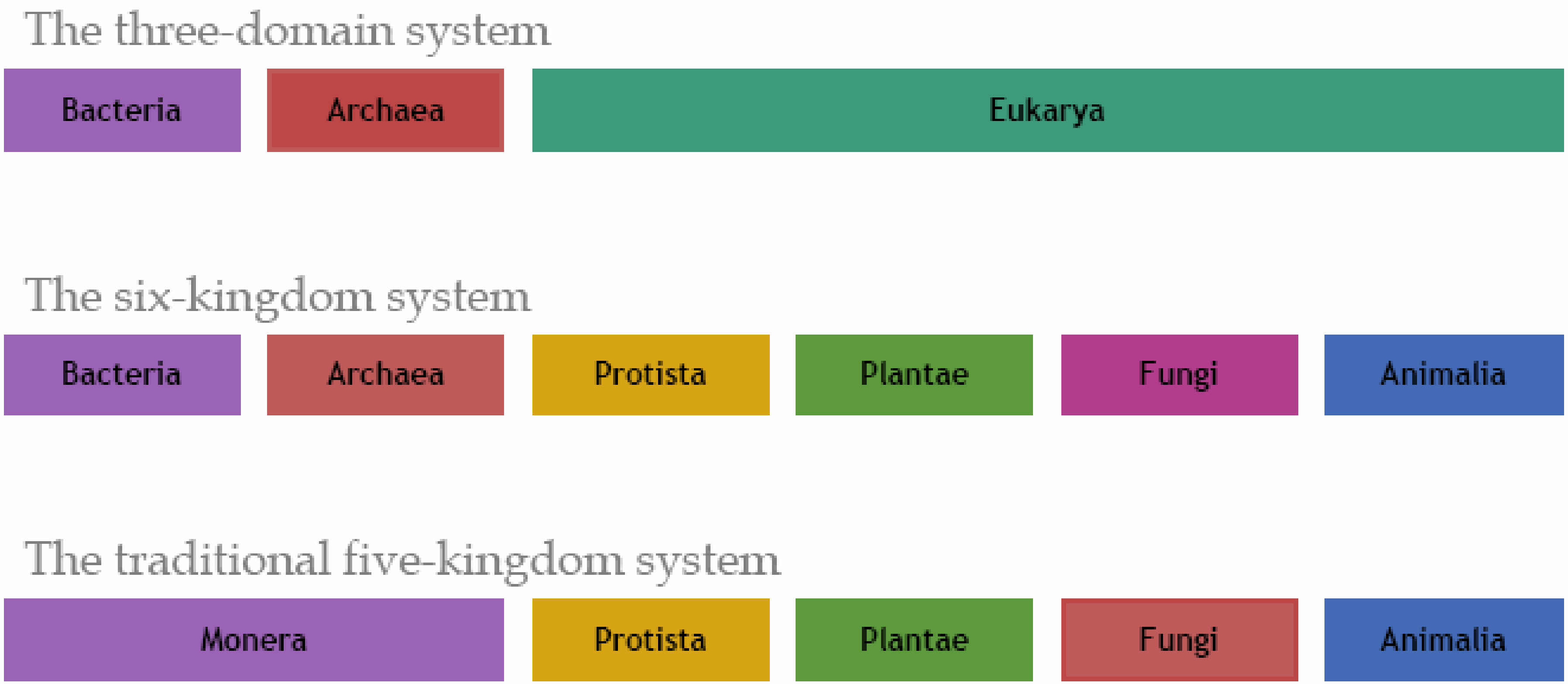
Ernst Haeckel (1834-1919)
classification in 3 kingdoms: protista, plantae, animalia

Robert Whittaker (1969)

classification in 5 kingdoms:

- Monera (prokaryotic cell)
- Protista (eukaryotic cell)
- Fungi (eukaryotic cells)
- Plantae (eukaryotic cells)
- Animalia (eukaryotic cells)

Kingdoms and Domains



The classification of living organisms

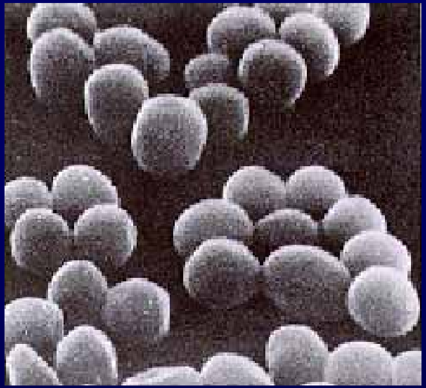
Domain Eubacteria

Eubacteria are microscopic **prokaryotic cells.**

Cyanobacteria, also called blue-green algae, are Eubacteria that have been living on our planet for over 3 billion years.

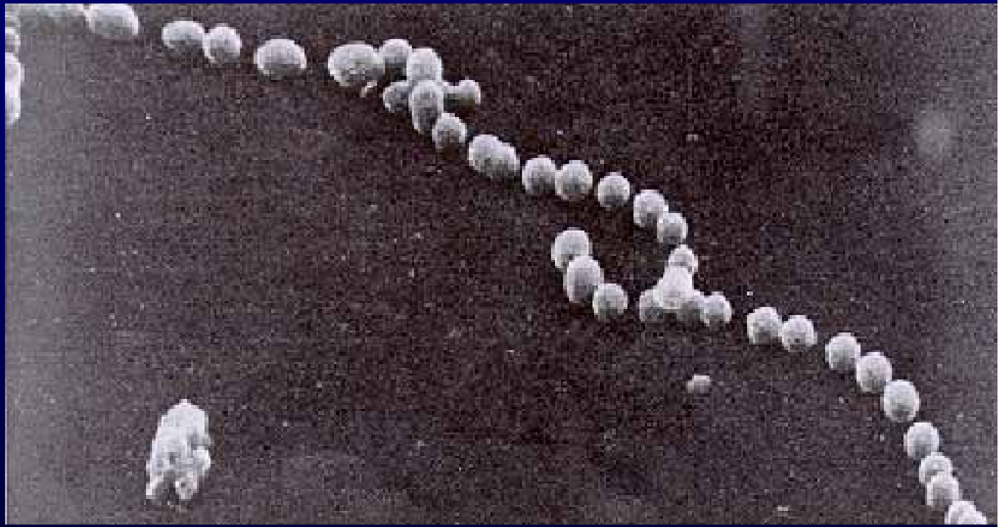
Through photosynthesis, which produces oxygen, billions of tiny bacteria were able to add oxygen to Earth's atmosphere.

Some Eubacteria can cause health problems like strep throat and food poisoning. **Bacteria** such as E.coli and Salmonella are sometimes found in undercooked meat and eggs and can make people sick.



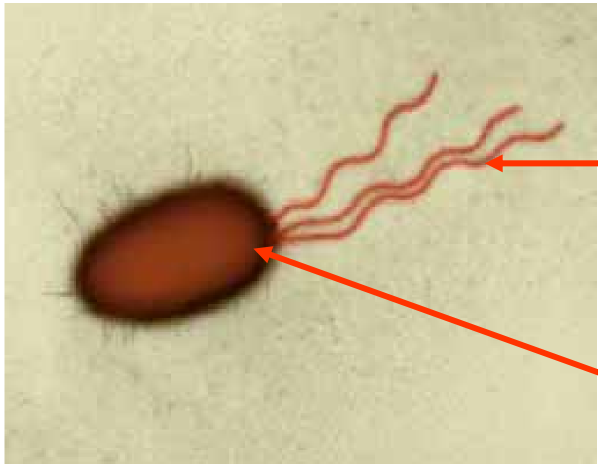
Staphylococcus

Escherichia coli



Streptococcus

Monera - Procariota



Filament extended into the external medium

Long ~10 μm, thin ~20 nm

Reversible rotary motor embedded in the cell wall

Helix – 2.5 μm pitch, 0.5 μm diameter

Speed ~100 Hz

E. coli size and speed yields very low Reynolds number regime (*Re* =10^{-4})

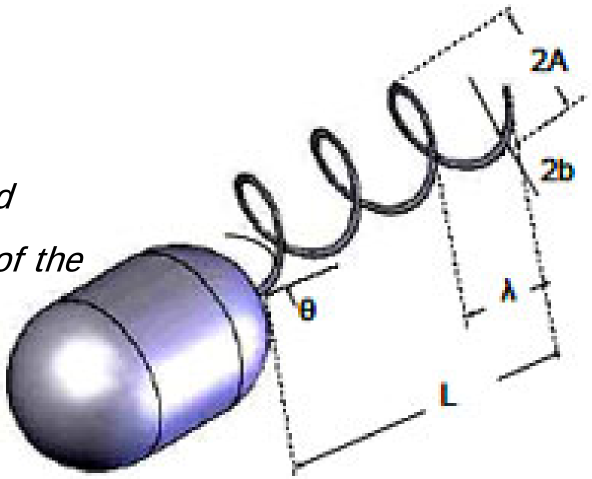
$$\mathrm{Re} = \frac{\rho V l}{\mu}$$

ρ = density of the fluid

μ = dynamic viscosity of the fluid

V = flow velocity

l = dimension of the object



Dimension of the swimming microrobot

Half of the thickness of the flagellum, b	23 µm
Amplitude of the flagellum, A	3.3 mm
Wavelength of the flagellum, λ	3.8 mm
Length of the flagellum, L	2.3 cm

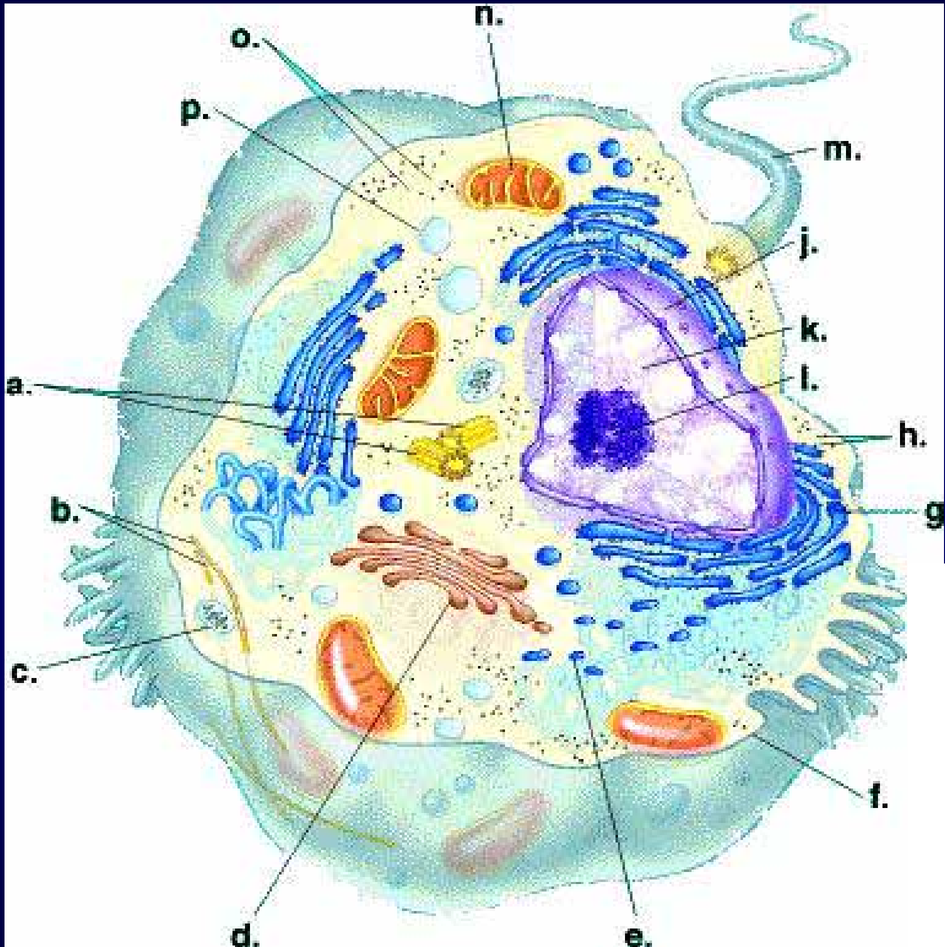
The classification of living organisms

Domain Eukaryota

Plants, animals, protists, and fungi are all members of the domain.

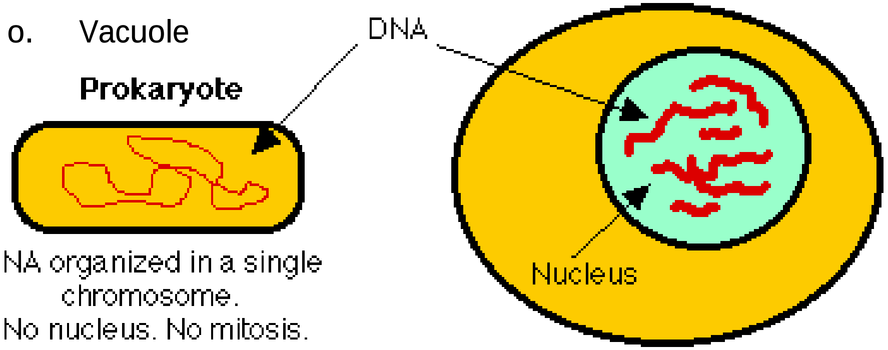
All members of the domain Euraryota have eukaryotic cells. And it is the only domain whose members have this cell type. Eukaryotic cells contain a special part called a nucleus that contains genetic material within chromosomes.

Eukaryotic Cell



a. Centrioles
b. Intermediate filamentes
c. Lysosome
d. Smooth endoplasmic reticulum
e. Ribosomes
f. Membrane cell
g. Rough endoplasmatic reticulum
h. Golgi body
i. Nucleolus
j. Nuclear envelope
k. Nucleus
l. Flagellus
m. Mitochindrion
n. Cytosol
o. Vacuole

Prokaryote **Eukaryote**



DNA organized in a single chromosome.
No nucleus. No mitosis.

Dim. 0.2-10 μm

DNA organized in multiple chromosomes inside a nucleus.
Mitotic division.

Dim. 10-100 μm

Differences between prokaryote and eukaryote

The classification of living organisms

Kingdom Plantae

Kingdom Plantae contains almost 300,000 different species of plants. In the process known as "**photosynthesis**", plants use the energy of the Sun to convert water and carbon dioxide into food (sugars) and oxygen. Photosynthesis by plants provides almost all the oxygen in Earth's atmosphere. Because plants can **make their own food (autotrophs)**, they are the first step to many food chains in the world.

The first plants lived on land about 450 million years ago. Since then, plants have taken on many forms and are found in most places on Earth. Plants can live in dry places or wet places, low places or high places, hot places or cold places. Humans can't live in a world without plants.

The classification of living organisms

Kingdom Animalia

With over 9 million species, Kingdom Animalia is the largest of the kingdoms in terms of its species diversity.

Over half of all the animal species belong to a group of animals known as arthropods. Arthropods include animals such as centipedes, crabs, insects, and spiders.

Animals are "multicellular" (composed of many cells). In most animals, these cells are organized into tissues that make up different organs and organ systems. All animals are **heterotrophs** (= "other feeder"), meaning that they **must get their food by eating other organisms, such as plants, fungi, and other animals**. In addition, all animals require oxygen for their metabolism, can sense and respond to their environment, and have the capacity to reproduce sexually (though many reproduce asexually as well). During their development from a fertilized egg to adult, all animals pass through a series of embryonic stages as part of their normal life cycle.


Porifera
Ctenophora
Ctenophora
Cnidaria
Nematoda
Platyhelminthes


Chordata
Annelida
Arthropoda
Echinodermata
Molluska

The classification of living organisms

Kingdom Protista

Members of the Kingdom Protista are the **simplest of the eukaryotes**. Some members of Kingdom Protista are unicellular, others are colonial, and yet others are multicellular. Protists are an unusual group of organisms that were put together because they don't really seem to belong to any other group. Some protists perform **photosynthesis** like plants while others move around and **act like animals**, but protists are neither plants nor animals, and they're not fungi either. Protists are grouped into three major, unofficial categories based on means by which they obtain nutrition. These are the Protozoa, the Algae, and the Fungus-like Protists.

Kingdom Protista

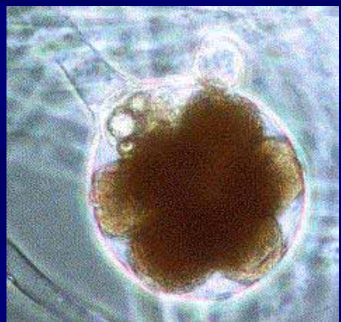
Animal-Like (Protozoans)

Amoeba

Paramecium

Giardia

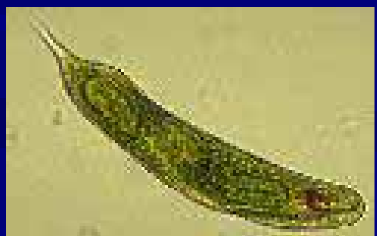
Fungus-Like



Water Mold

Slime Mold

Plant-Like

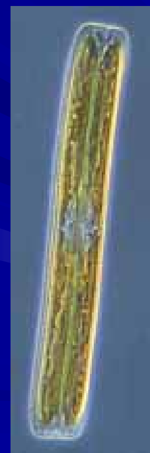


Euglena

Dinoflagellates

Green Algae

Brown Algae



Diatom

The classification of living organisms

Kingdom Fungi

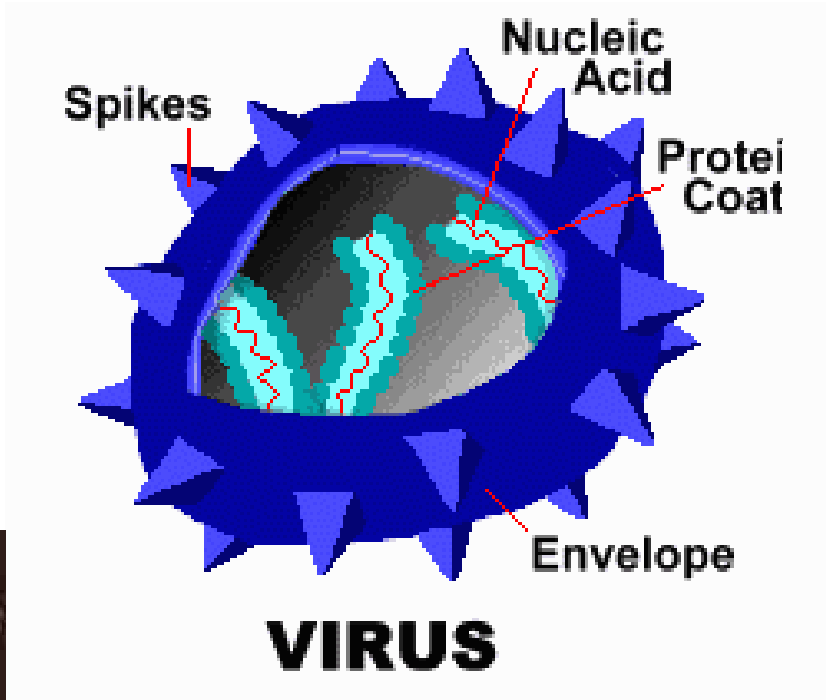
Though the appearance of many fungi may resemble plants, they are probably more closely related to animals. Fungi **are not capable of performing photosynthesis**, so must get their nourishment from other sources. Many fungi absorb nutrients directly from the soil. Many others feed on dead and decaying organisms and therefore have an important role in the recycling of nutrients in natural systems. Still others feed on living organisms.

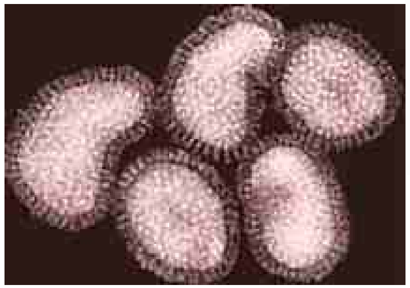
Fungi come in a wide variety of sizes and forms, and many have great **economic importance**. Tiny, one-celled yeasts are important for baking breads and fermenting wines, beers and vinegars. Many medicines are produced with the help of fungi, most notably, the antibiotic, Penicillin.

Virus

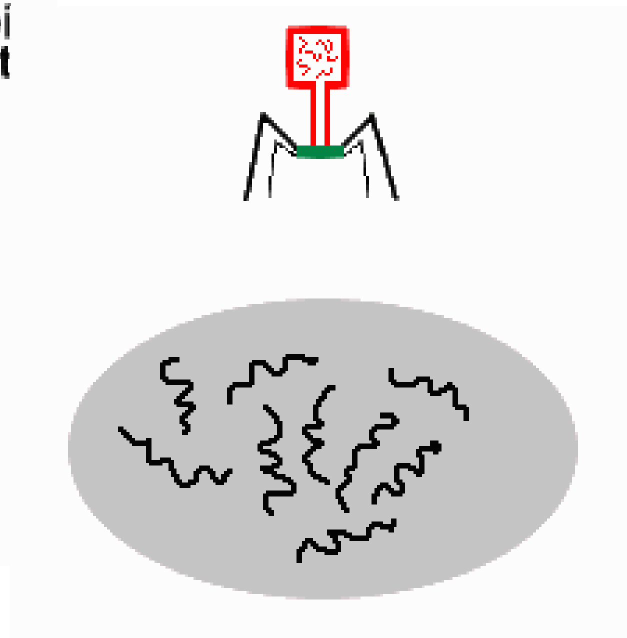
Are viruses alive?

Viruses are parasites that skirt the boundary between life and inert matter. They have the same kinds of protein and nucleic acid molecules that makes up living cells but require the assistance of these cells to replicate and spread. Viruses are much smaller, with lengths measured in nm. All viruses are made up of a core of genetic material (DNA, or RNA), surrounded by a protein coat.



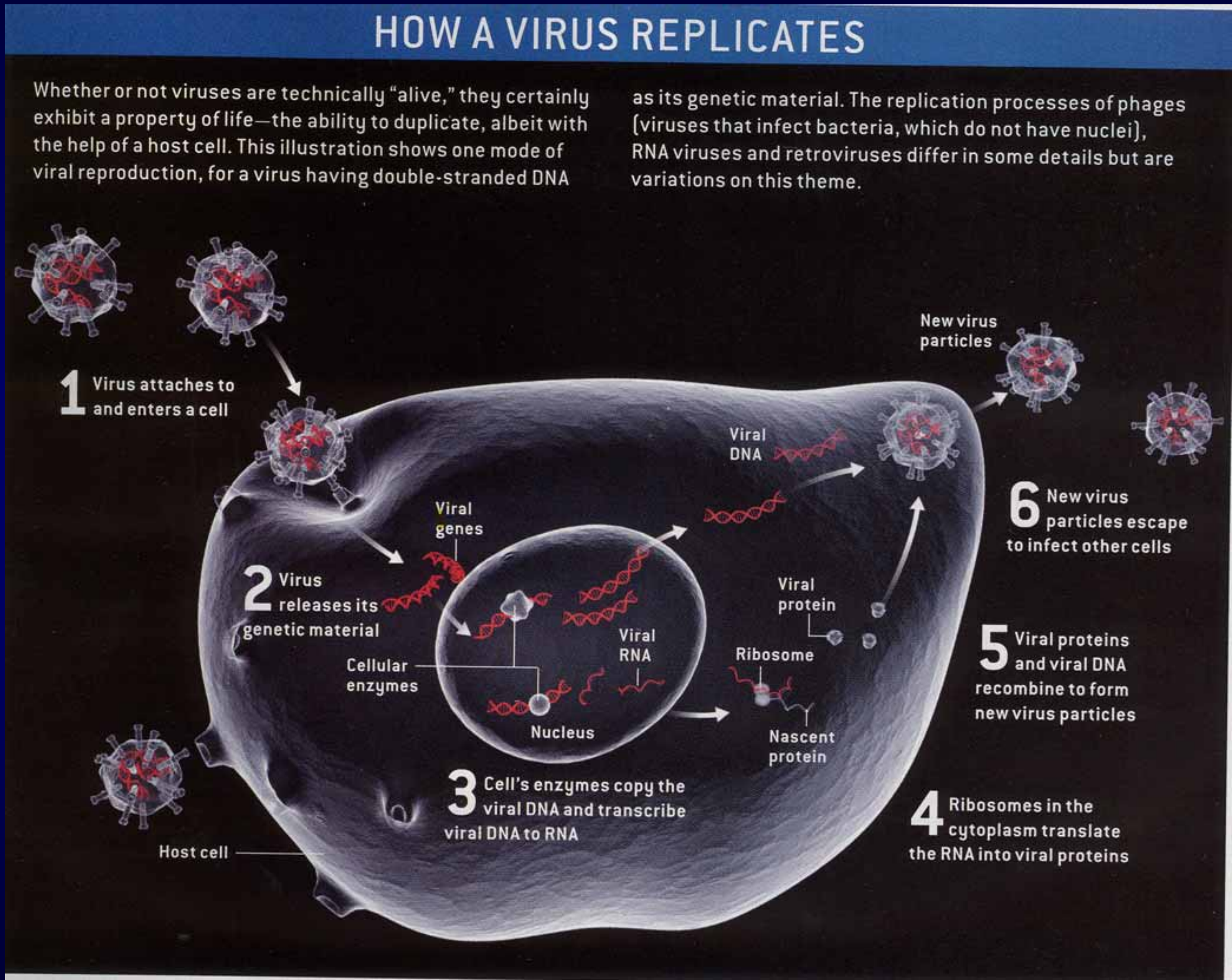


Flu Virus



Bacteriophage

Virus


HOW A VIRUS REPLICATES
Whether or not viruses are technically "alive," they certainly exhibit a property of life—the ability to duplicate, albeit with the help of a host cell. This illustration shows one mode of viral reproduction, for a virus having double-stranded DNA as its genetic material. The replication processes of phages (viruses that infect bacteria, which do not have nuclei), RNA viruses and retroviruses differ in some details but are variations on this theme.
1 Virus attaches to and enters a cell
2 Virus releases its genetic material
Viral genes
Cellular enzymes
Nucleus
Viral RNA
Viral DNA
3 Cell's enzymes copy the viral DNA and transcribe viral DNA to RNA
Ribosome
Nascent protein
Viral protein
4 Ribosomes in the cytoplasm translate the RNA into viral proteins
5 Viral proteins and viral DNA recombine to form new virus particles
New virus particles
6 New virus particles escape to infect other cells
Host cell

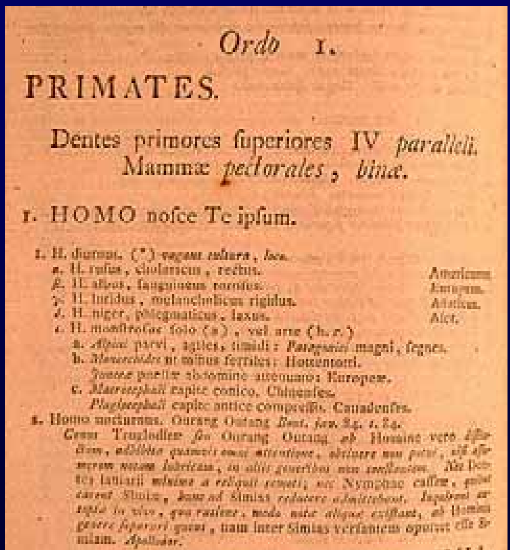
Binomial Nomenclature

- Carolus von Linnaeus
- Two-word naming system
  - Genus
    - Noun, Capitalized, Underlined or Italicized
  - Species
    - Descriptive, Lower Case, Underlined or Italicized

Carolus von Linnaeus
(1707-1778)

Swedish scientist who laid foundation for modern taxonomy

The Linnaeus's classification



Ordo I.

PRIMATES.

Dentes primores superiores IV paralleli.
Mammæ pectorales, binæ.

1. HOMO nosce Te ipsum.

Carl von Linnè (1707-1778)

Swedish naturalist (botanic scientist)

Creationistic theory: his system for naming, ranking, and classifying organisms is still in wide use today (with many changes).

Species subsist as metaphysic entities or "types" and individuals are copies of the model.

1735 Systema naturae

Natural classification, distributes species of organisms in real entities, which could be grouped into higher categories:

Species, Genus, Orders, Classes, Kingdom.

(the denomination of Phylum has been introduced by *Georges Cuvier*)

Two Kingdoms: Animalia and Plantae

The Linnaeus's classification

Linnaeus simplified naming immensely by designating one Latin name to indicate the genus, and one as a "shorthand" name for the species. The two names make up the **binomial** ("two names") species name.

Genus species

Capitalized — ***italicized***

lower case — ***italicized***

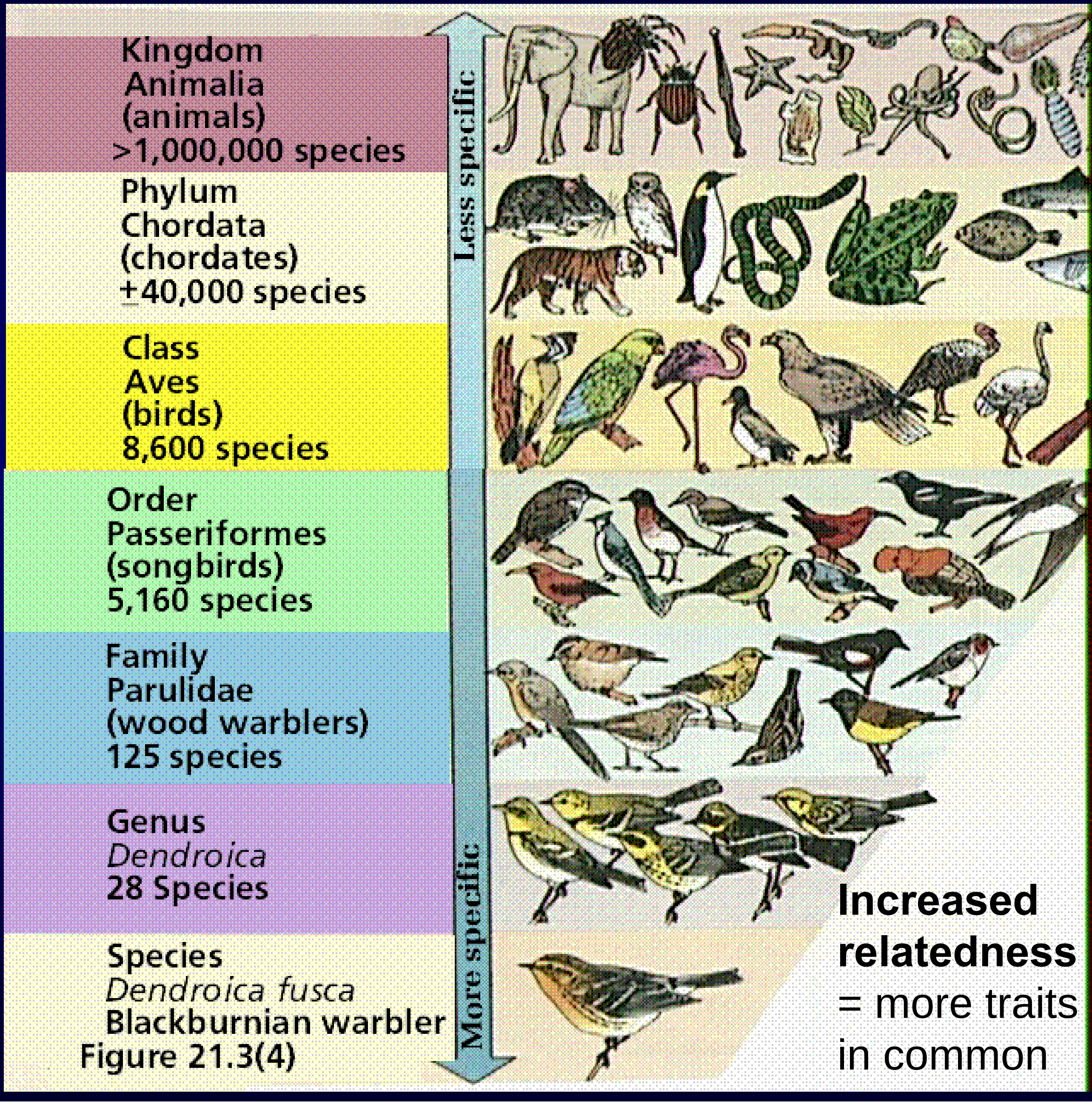
Usually Latin

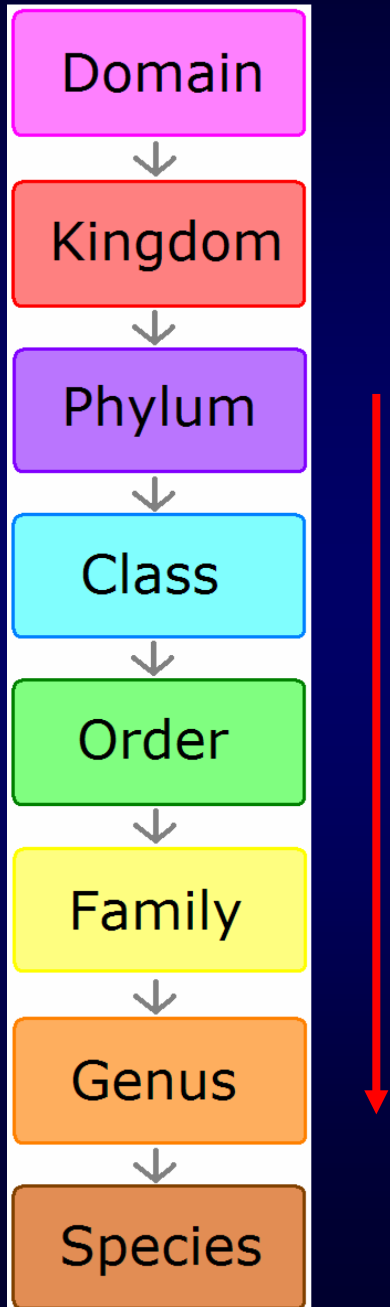
Examples: *Felis domesticus; Homo sapiens*

CLASSIFICATION OF *Homo sapiens*

- **DOMAIN EUKARYA**
- **KINGDOM ANIMALIA**
- **PHYLUM CHORDATA** — Animals having, at some time in their life cycle, a notochord, a hollow dorsal nerve cord, pharyngeal slits or pouches.
- **SUBPHYLUM VERTEBRATA**
- **CLASS MAMMALIA** — Vertebrate animals characterized by warm-blooded, the production of milk in female mammary glands and the presence of hair.
- **ORDER PRIMATE** — Animals with five fingers, a generalized dental pattern, fingernails, and opposing thumbs (includes lemurs, monkeys, and apes).
- **FAMILY HOMINIDAE** — Flat face, frontal eyes, color-vision, biped locomotion, erect posture (apes, which includes humans, chimpanzees, gorillas, and orangutans).
- **GENUS *Homo*** — Big brain, language, long childhood.
- **SPECIES *Homo sapiens*** — Chin prominent, high forehead, hairs shed on the body.

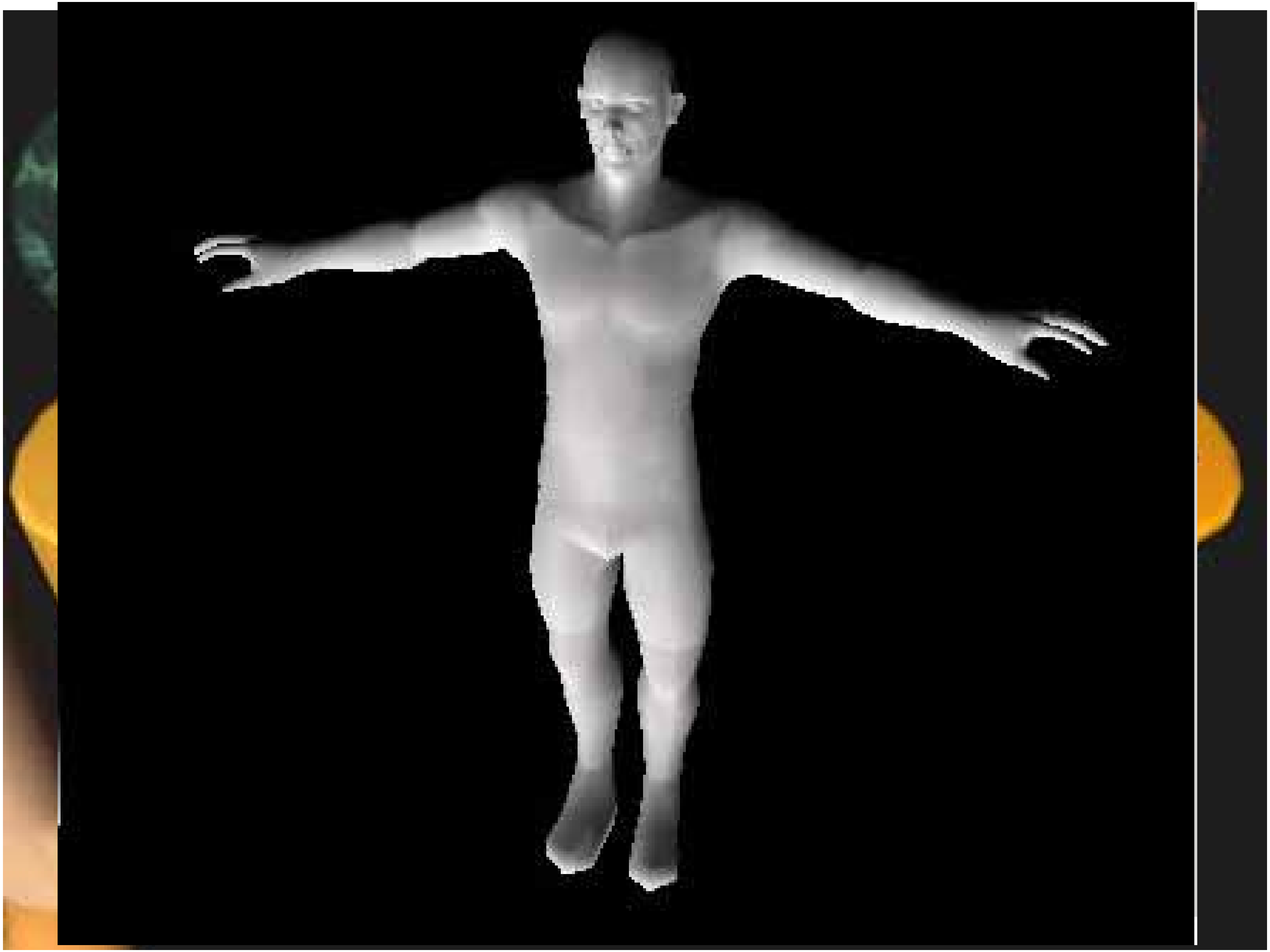
The beings classification





III PARTE

FONDAMENTI DI ZOOLOGIA



The Animalia Kingdom

INVERTEBRATES

95%

(Animals without spinal cord)

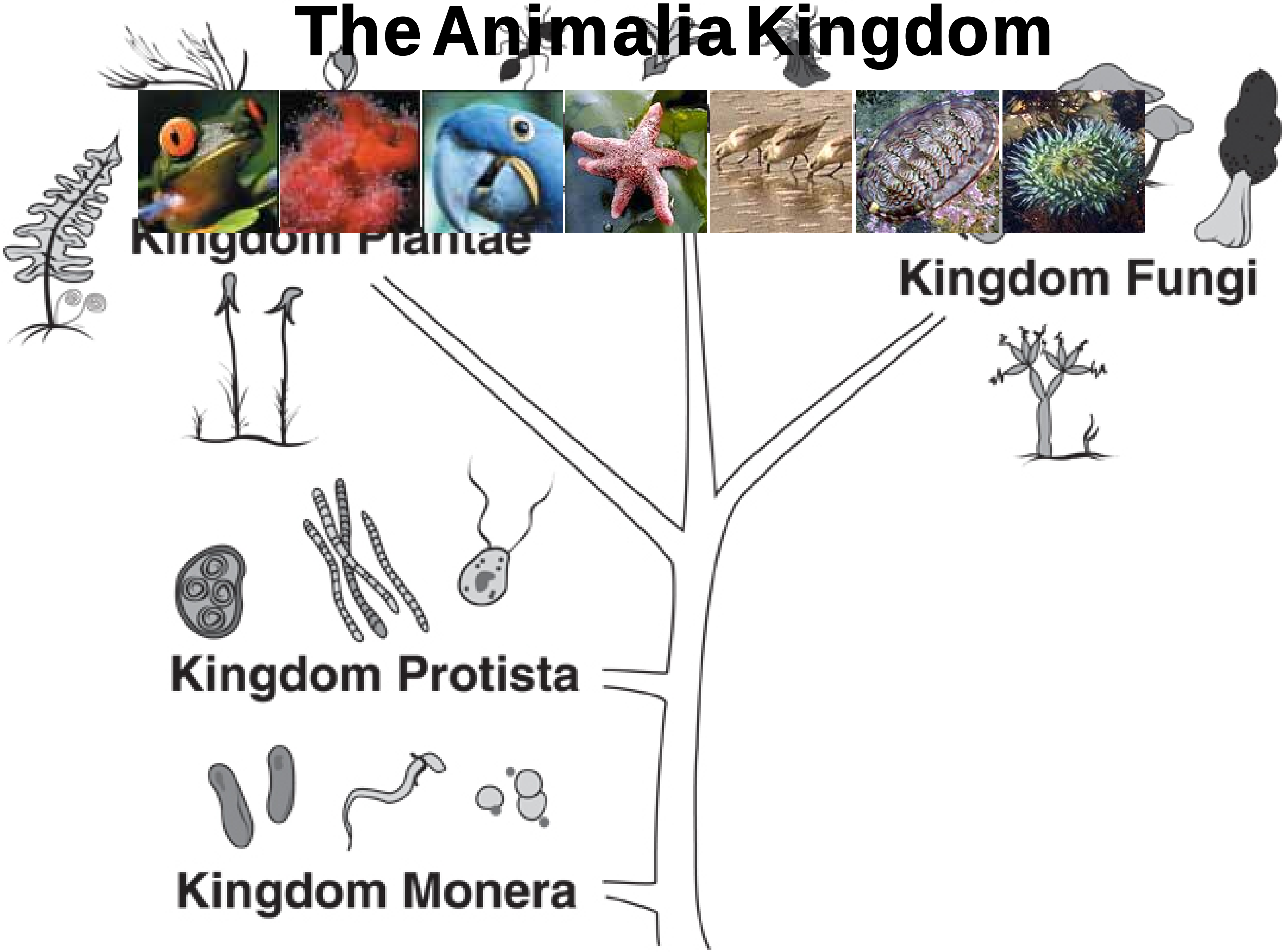
VERTEBRATES

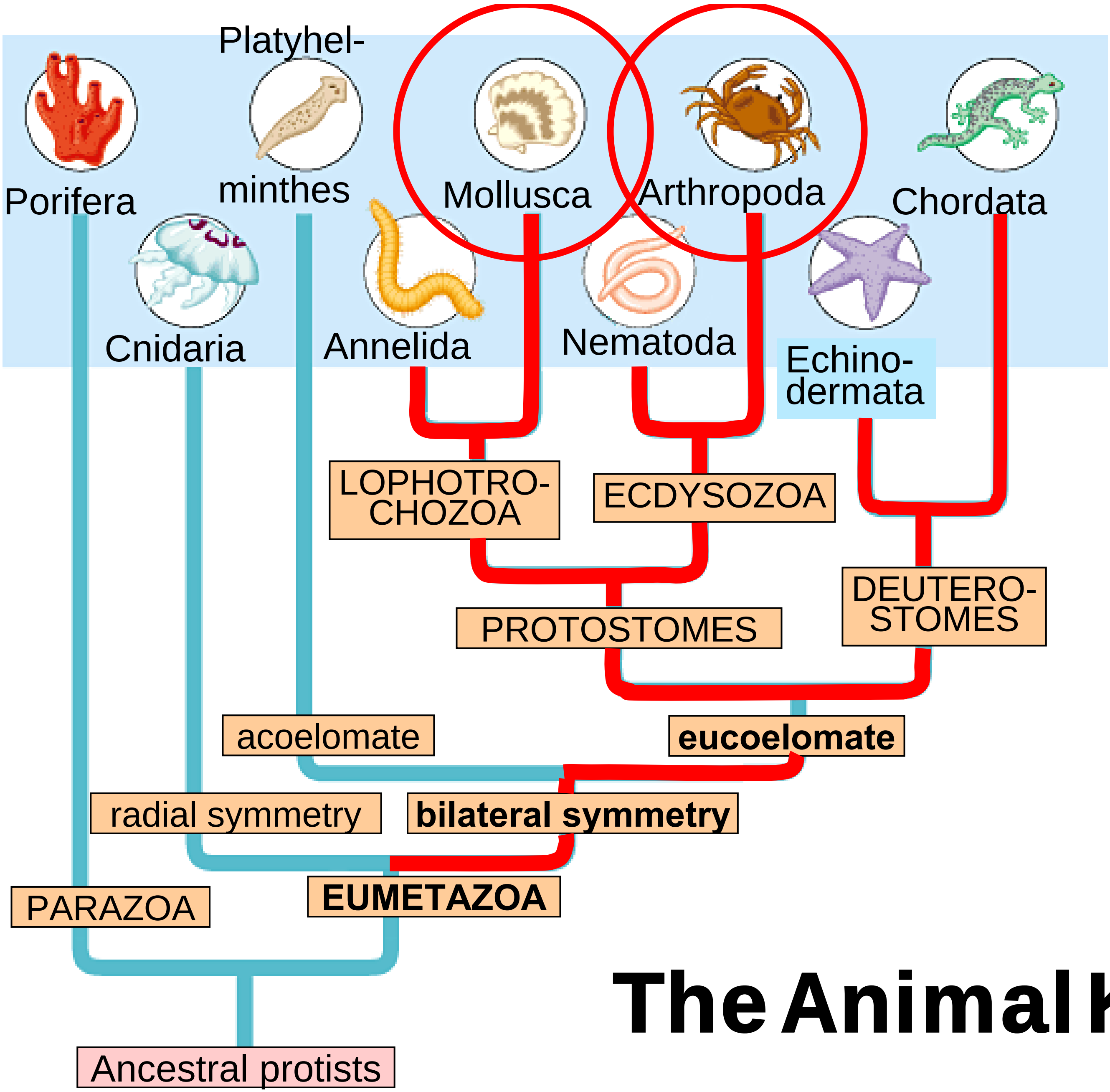
5%

(Animals with spinal cord)

Sponges ***(phylum Porifera)***
Jellyfish and sea anemones ***(phylum Cnidaria)***
Flatworms ***(phylum Platyhelminthes)***
Roundworms ***(phylum Nematoda)***
Segmented worms ***(phylum Annelida)***
Insects, spiders and crustaceans ***(phylum Arthropoda)***
Snails, clams and squid ***(phylum Mollusca)***
Starfish and sea urchins ***(phylum Echinodermata)***

The Animalia Kingdom



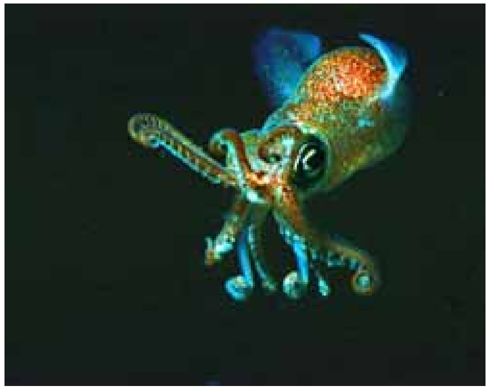


The Animal Kingdom

Phylogenetic Tree

Mollusca - snails, slugs, clams, octopuses




Phylum Mollusca

The molluscs rival the arthropods in their diversity of body forms and sizes, as well as their ecological success. The phylum also provides some of the most familiar animals, such as snails, clams, mussels, squids, and octopus. The phylum Mollusca also includes lesser known forms such as the chitons, tusk shells, solenogasters, among others. Approximately 50,000 species of Molluscs have been described, and because of the shelled forms they have left a rich fossil record.

Class Cephalopoda (octopuses and squids)
Class Gastropoda (gastropods, slugs, and snails)
Class Bivalvia (bivalves and clams)
Class Scaphopoda (tusk shells)
Class Monoplacophora
Class Polyplacophora
Class Aplacophora

Rationale: octopus arm amazing features

- Infinite number of degrees of freedom
- All-direction bending
- Elongation capability
- Variable stiffness
- Distributed control

Studying the octopus and building a robotic octopus

Expected results:
- new **science** (new knowledge on the octopus biomechanics, motor control, sensory-motor behaviour)
- new **robotics technologies** for sensing, actuation, and control

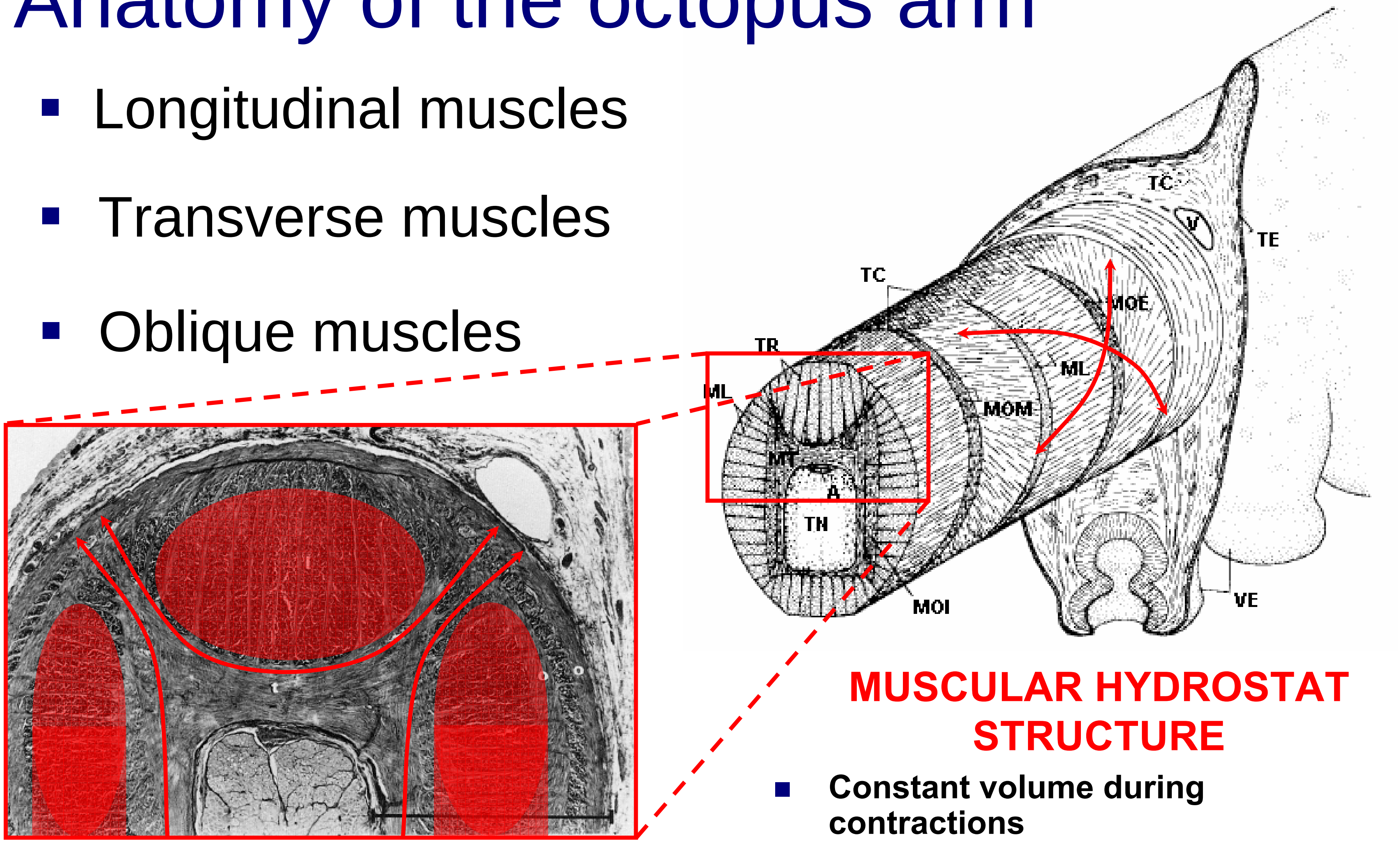
The Octopus and its limbs

The *Octopus vulgaris* is an invertebrate (mollusc) sea creature, with a large soft head, eight limbs (tentacles) and two rows of suckers on the underside of each limb

The *tentacle* is capable of exerting forces with the sole use of muscles, **without any rigid structure**

Anatomy of the octopus arm

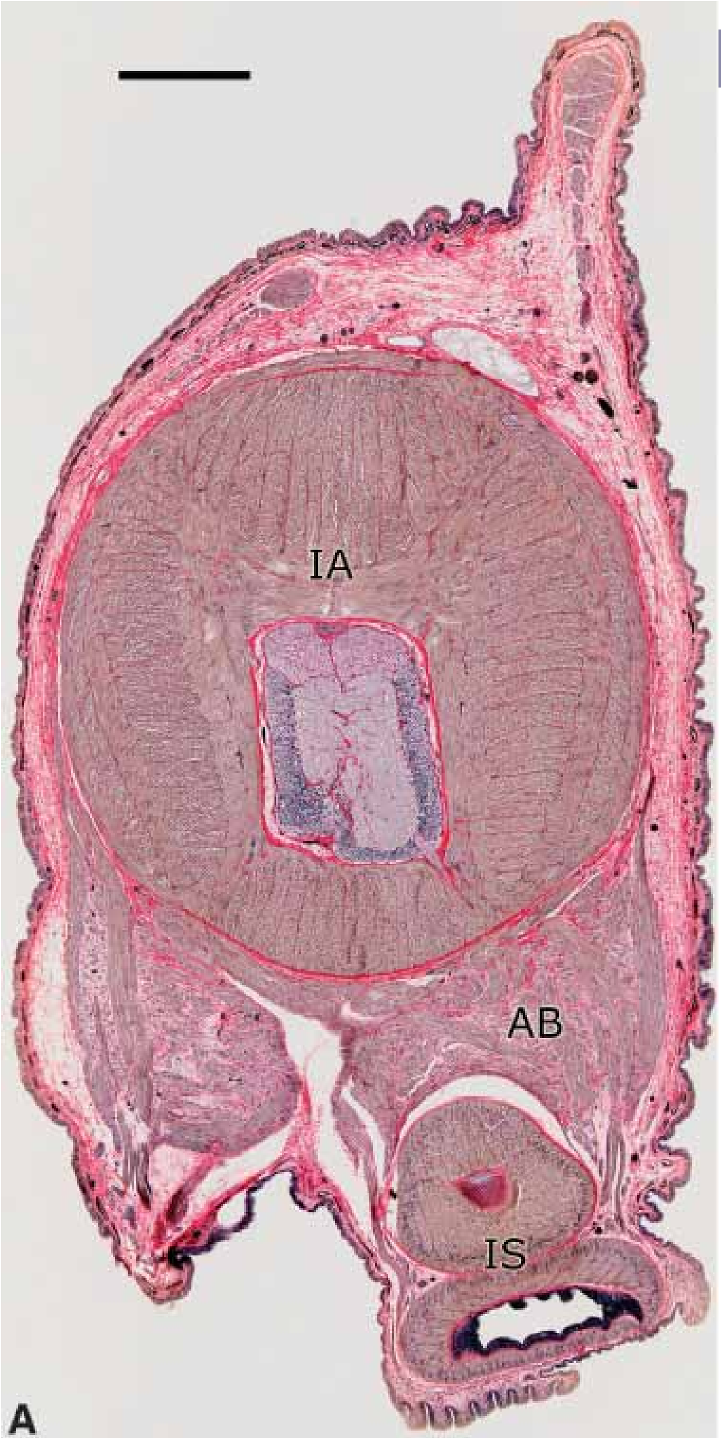
- Longitudinal muscles
- Transverse muscles
- Oblique muscles



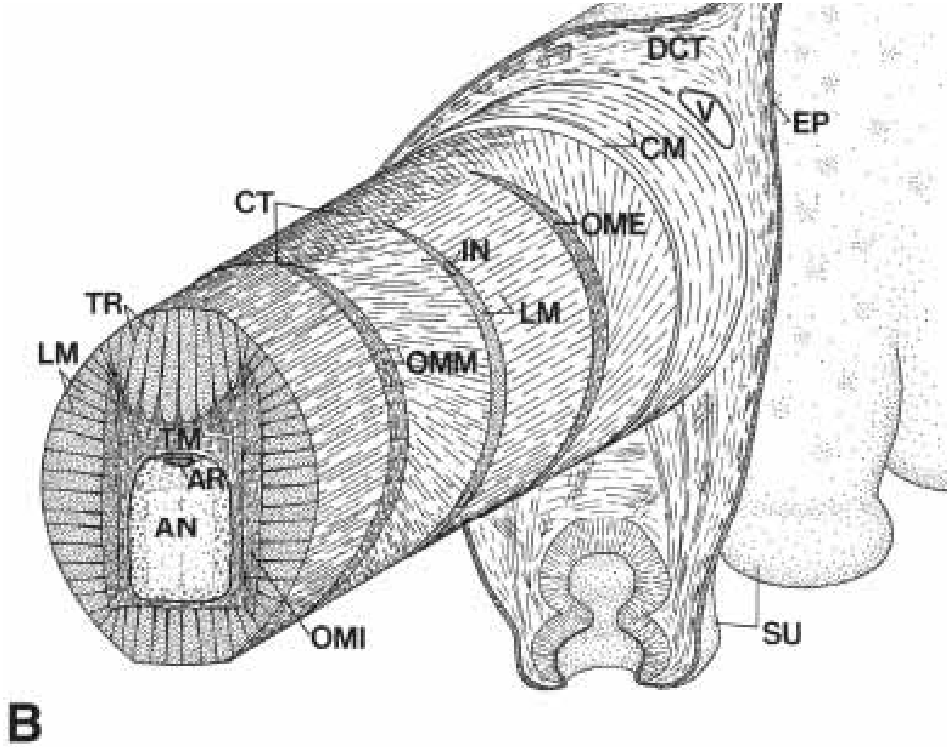
MUSCULAR HYDROSTAT STRUCTURE

- **Constant volume during contractions**
- **Peculiar to tentacles, mammal and reptile tongues, and elephant trunks**

Kier W. “The arrangement and function of Molluscan muscle”, The Mollusca, Vol. II, 1988



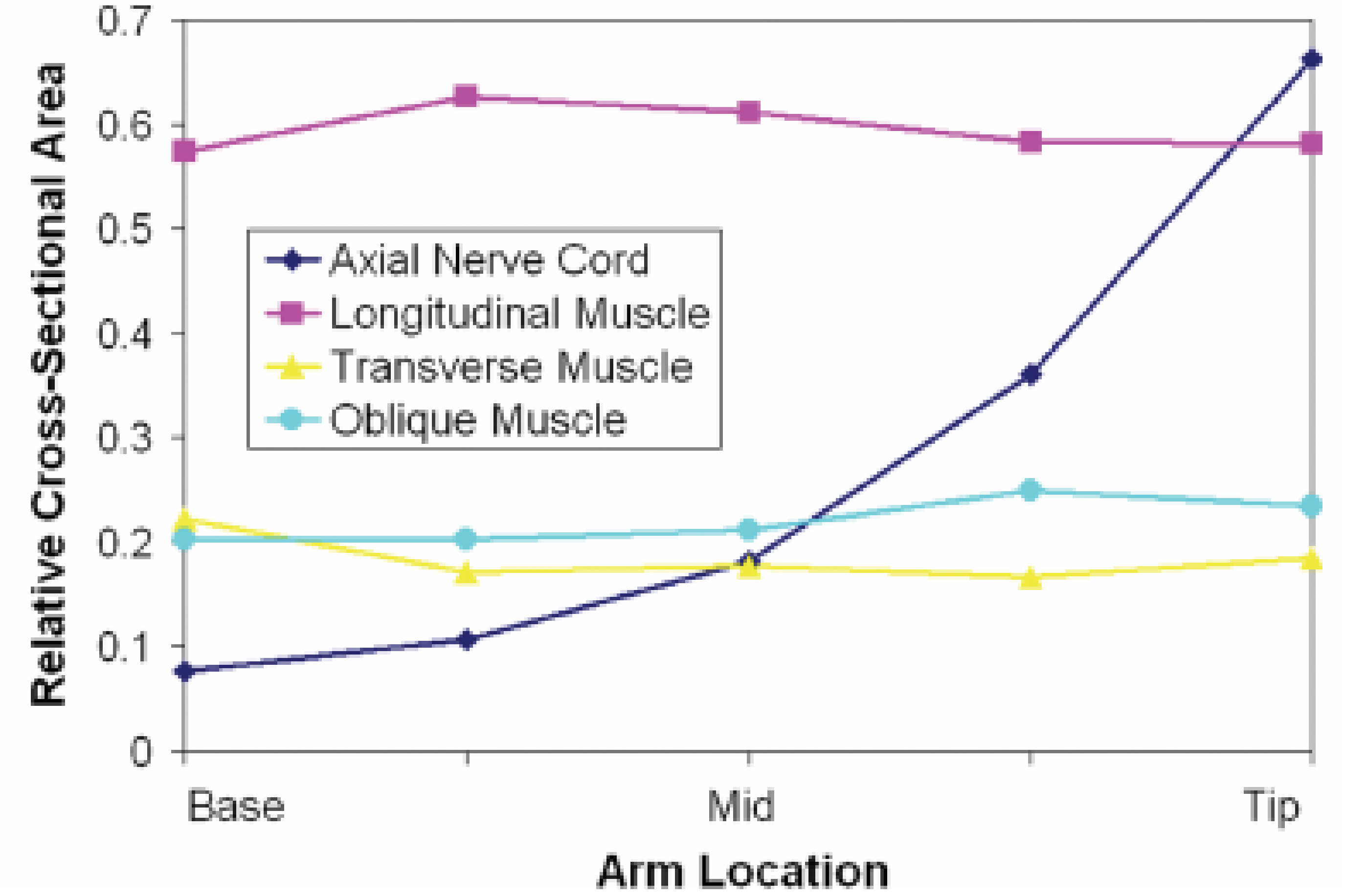
A: Transverse section of the arm of *Octopus bimaculoides* showing the three major subdivisions of the arm musculature: the **intrinsic arm musculature** (IA); the **intrinsic sucker musculature** (IS); and the **acetabulo-brachial musculature** (AB) connecting the arm and sucker musculature. Scale bar: 0.5 mm. **B:** Diagram of the arm of Octopus showing three-dimensional arrangement of muscle fibers and connective tissue fibers. **AN, axial nerve cord**; **AR, artery**; **CM, circumferential muscle layer**; **CT, connective tissue**; **DCT, dermal connective tissue**; **EP, epidermis**; **IN, intramuscular nerve**; **LM, longitudinal muscle fibers**; OME; external oblique muscle layer; **OMI, internal oblique muscle layer**; **OMM, median oblique muscle layer**; **SU, sucker**; **TM, transverse muscle fibers**; **TR, trabeculae**; **V, vein**.



~ **5 · 10^7 cellule nervose** all'interno dell'arto e ~**30000** fibre nervose che portano informazioni sensoriali e motorie da e verso il sistema nervoso centrale

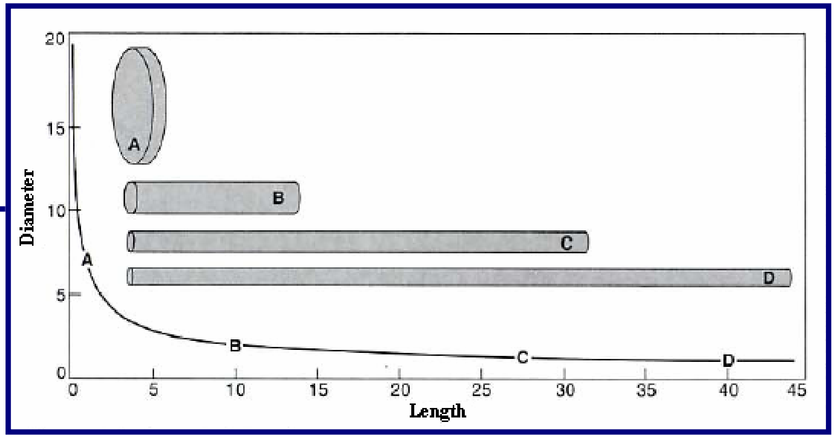
Anatomy of the octopus arm

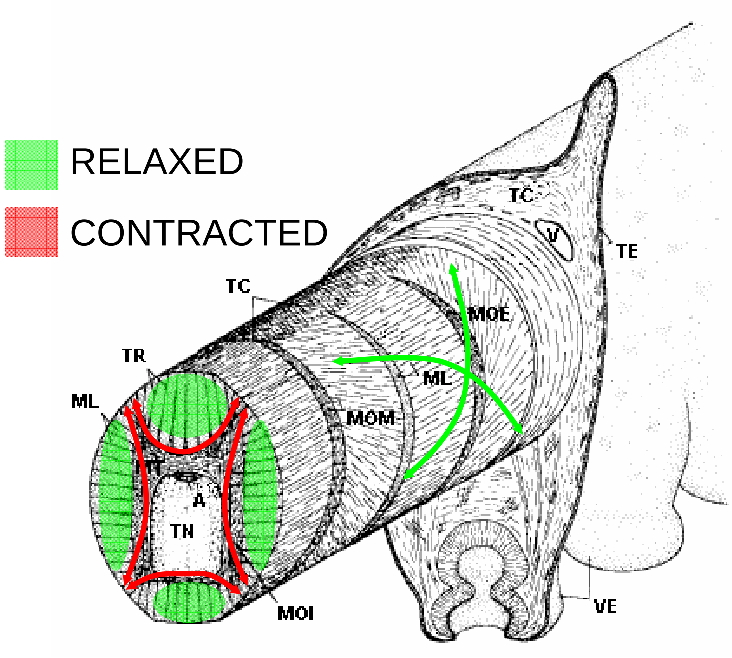
Plot of areas of the **axial nerve cord**, **longitudinal musculature**, **transverse musculature**, and **oblique musculature** divided by the total area of the intrinsic arm muscle (excluding the axial nerve cord) as observed in transverse sections obtained at identically spaced intervals down the length of an arm of *Octopus bimaculoides*. Note that the relative proportions of a transverse section of the various muscle masses remain **relatively constant along the length of the arm.** In contrast, the area of the axial nerve cord, expressed as a proportion of the intrinsic arm musculature, **increases dramatically from the base to the tip of the arm**.



Main functions of the octopus arm

- ELONGATION

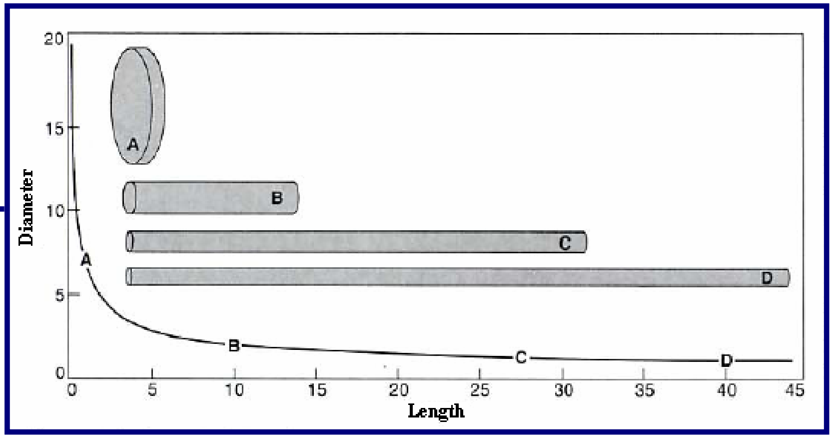


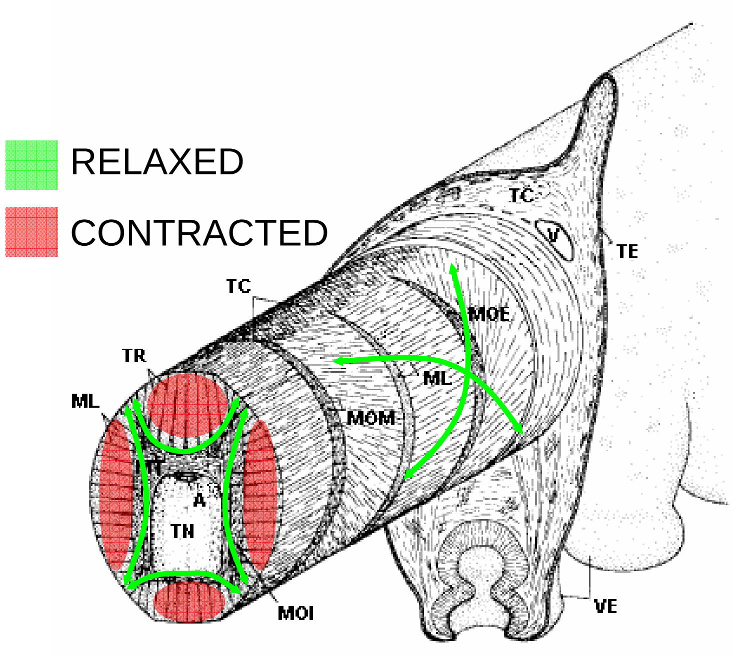


Kier W. "The arrangement and function of Molluscan muscle", The Mollusca, Vol. II, 1988

Main functions of the octopus arm

- ELONGATION
- SHORTENING





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Main functions of the octopus arm

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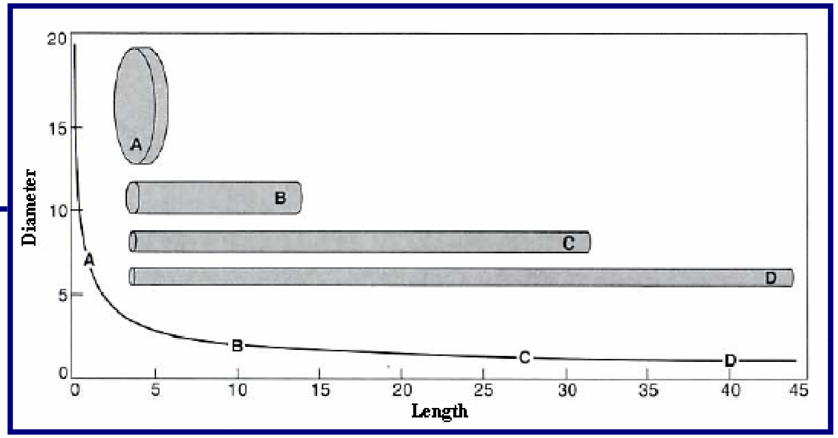
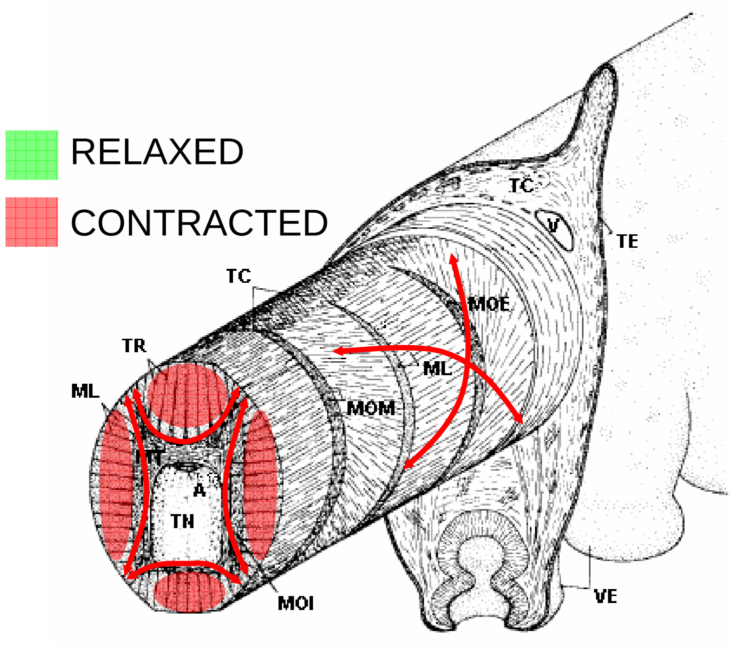


- STIFFENING



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Main functions of the octopus arm

- ELONGATION
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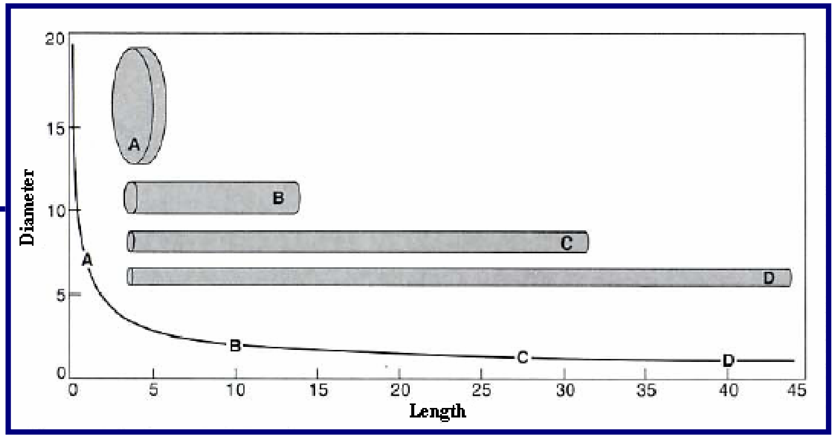
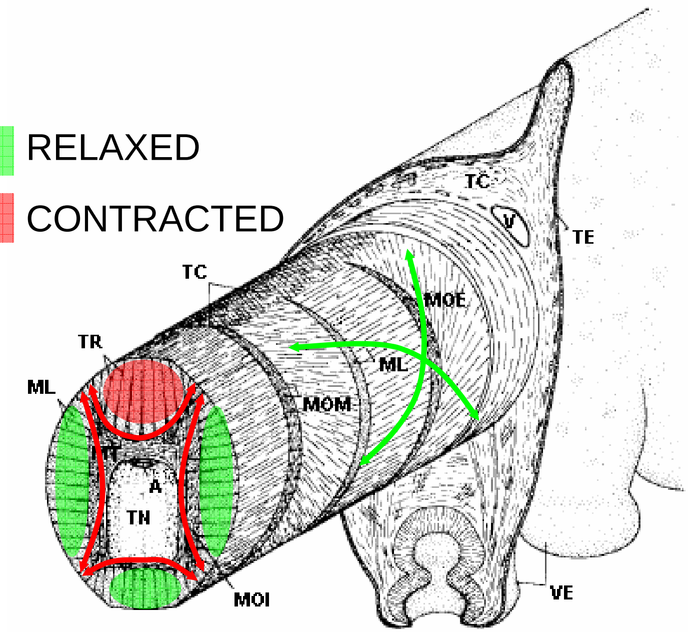
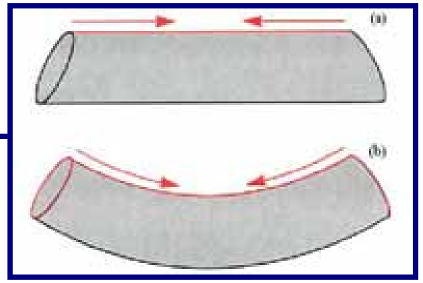


RELAXED

CONTRACTED



- STIFFENING
- BENDING



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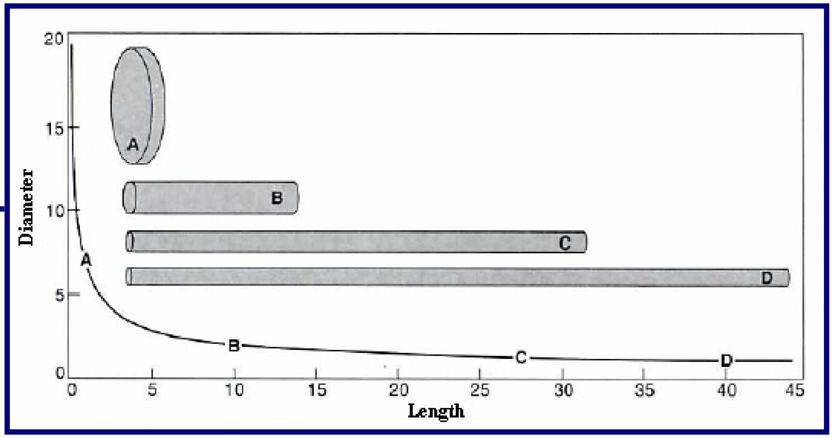
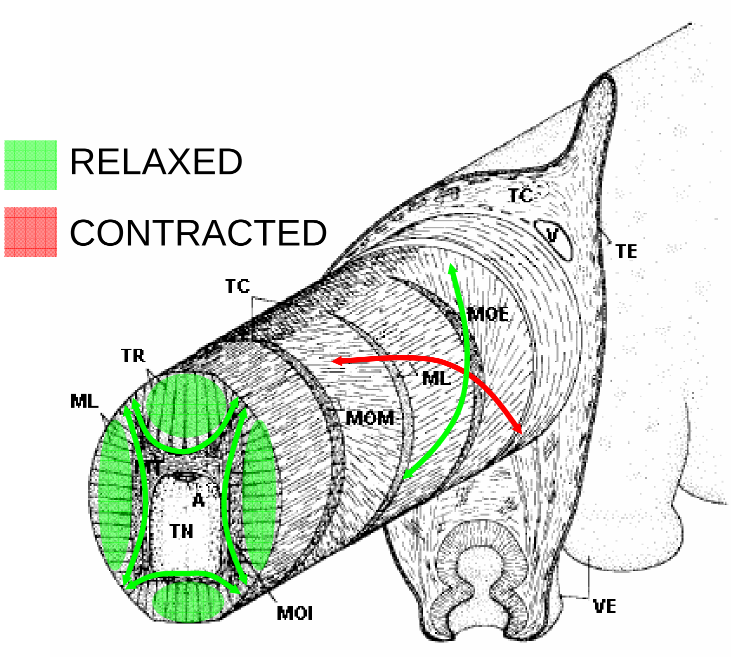
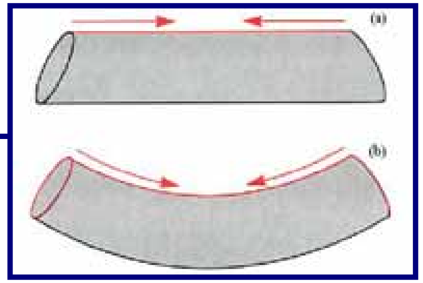
Main functions of the octopus arm

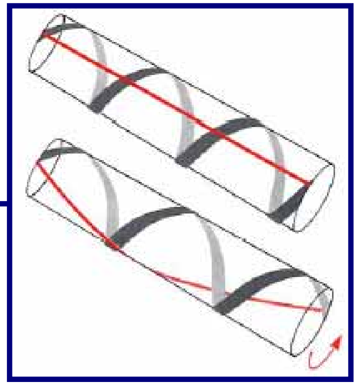
- ELONGATION
- SHORTENING





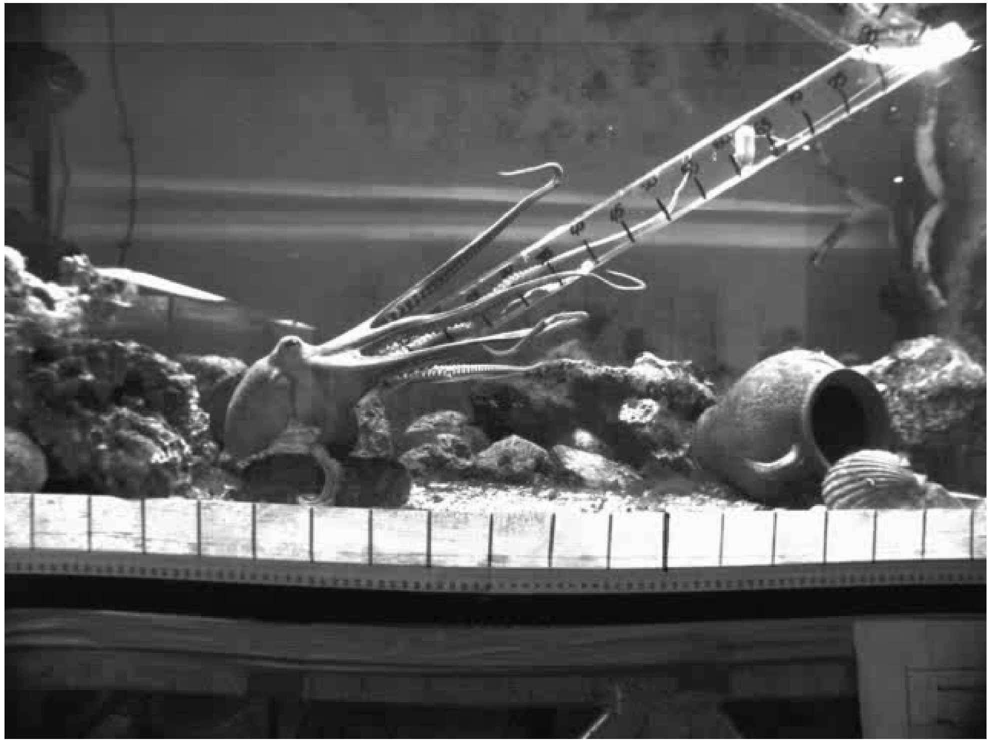
- STIFFENING
- BENDING
- TORSION





Kier W. "The arrangement and function of Molluscan muscle", The Mollusca, Vol. II, 1988

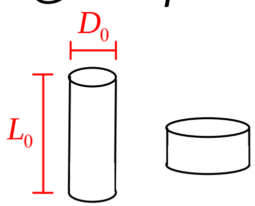
Experimental and theoretical analysis of octopus arm elongation



Video taken with high-speed cameras @100 fps

Octopus arm length variation:

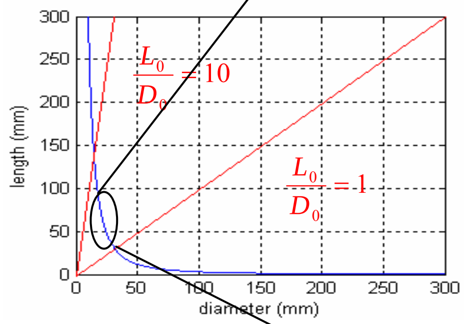
- 25 cm at rest
- 65 cm at max elongation



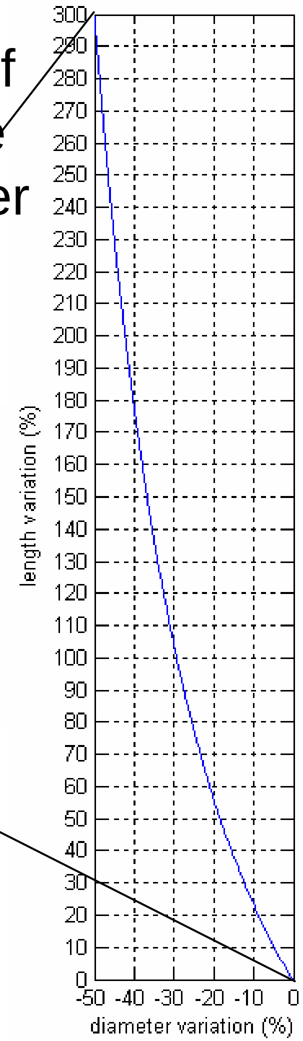
$$\frac{\Delta L}{L_0} = 1.6$$

260 % of elongation

Relative variation of length *L* vs. relative variation of diameter *D* in a constant volume cylinder



$$\frac{\Delta L}{L_0} = \frac{1}{\left(\frac{\Delta D}{D_0} + 1\right)^2} - 1$$



Biomeccanica dei movimenti complessi

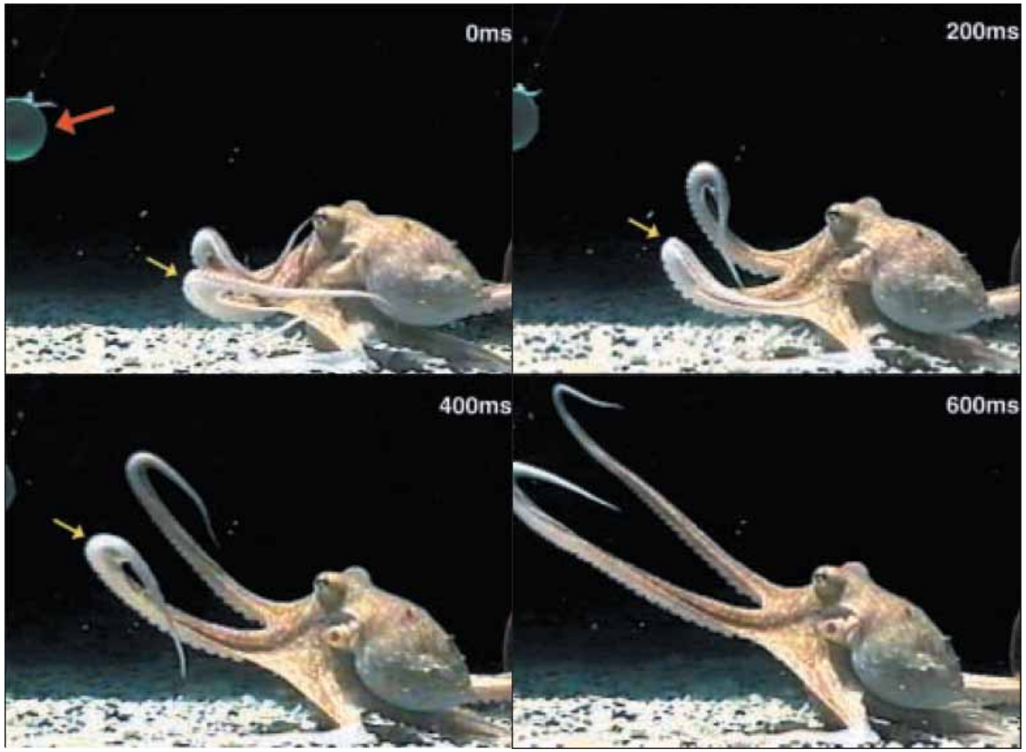
Reaching

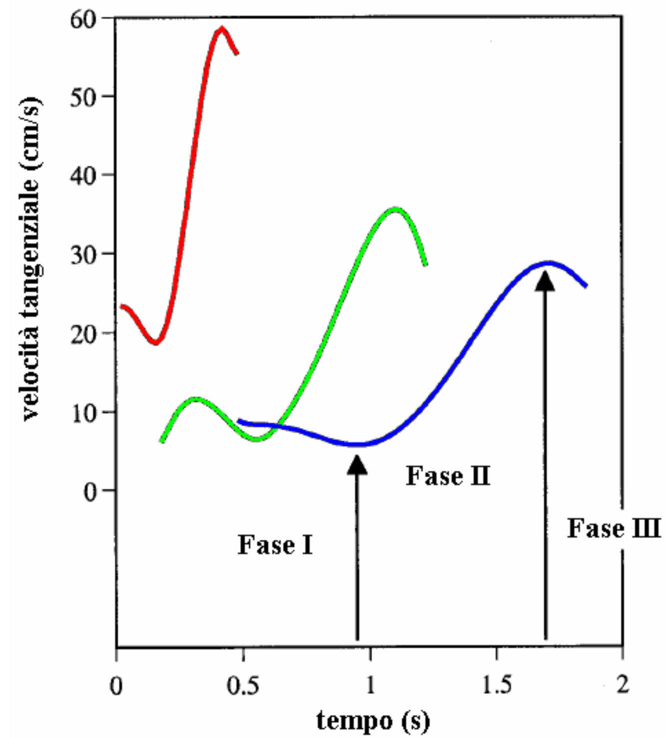
I movimenti di base descritti possono essere usati singolarmente o in combinazione e formare movimenti molto più complessi. Per fare questo, il polpo adotta delle strategie nell'eseguire questi movimenti:

- **Stereotipazione del movimento**, che gli permette di ridurre drasticamente il numero di gradi di libertà da controllare
- **Divisione dei "lavori"**, tra sistema nervoso centrale e periferico

Il movimento di reaching viene utilizzato **per raggiungere ed afferrare gli oggetti che entrano nel campo visivo dell'octopus**. È uno dei movimenti più utilizzati ed è riassumibile in due passi fondamentali:

1. Viene **creata una curva in un punto qualunque lungo il tentacolo**; la curvatura avviene sempre **dorsalmente** in modo da presentare il lato ventrale e le ventose nella direzione di estensione del tentacolo
2. La **piega si propaga** lungo il tentacolo fino all'apice mentre la **parte prossimale, già investita dallo stimolo, rimane rigida ed estesa.**



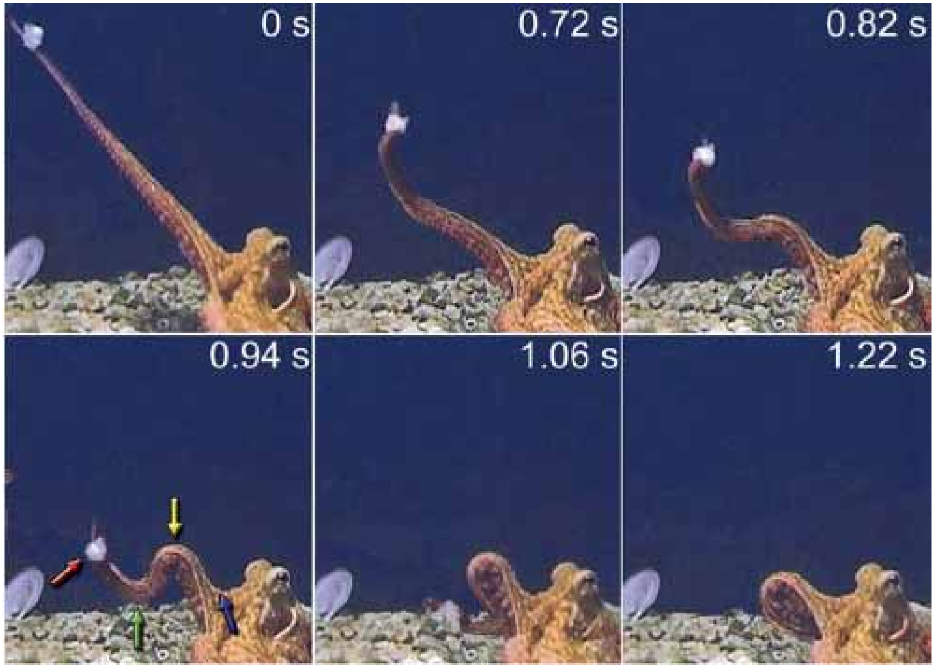


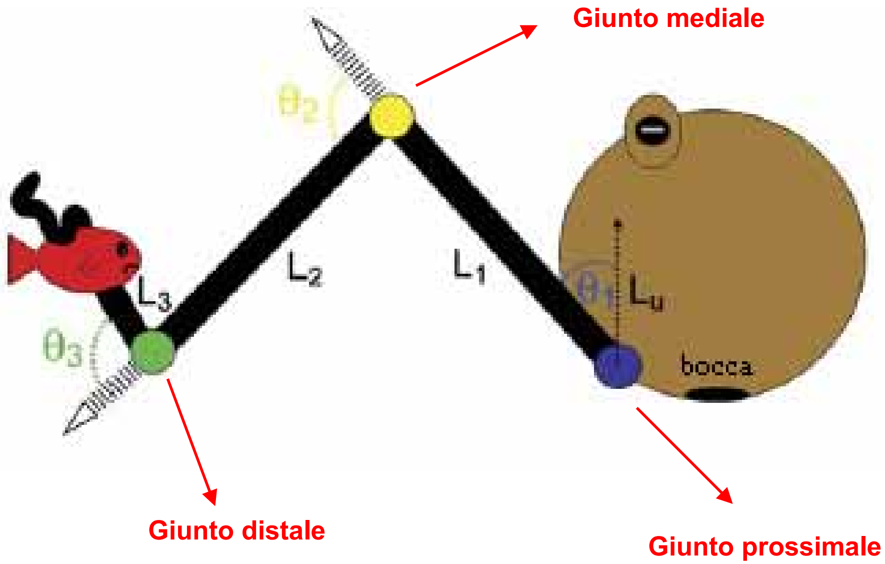
Biomeccanica dei movimenti complessi

Fetching

Un altro movimento complesso che l'octopus è in grado di attuare è quello di **fetching**, cioè avvicinare alla **bocca** ciò che è stato **raggiunto e afferrato in un qualsiasi punto del tentacolo durante il movimento di reaching.**

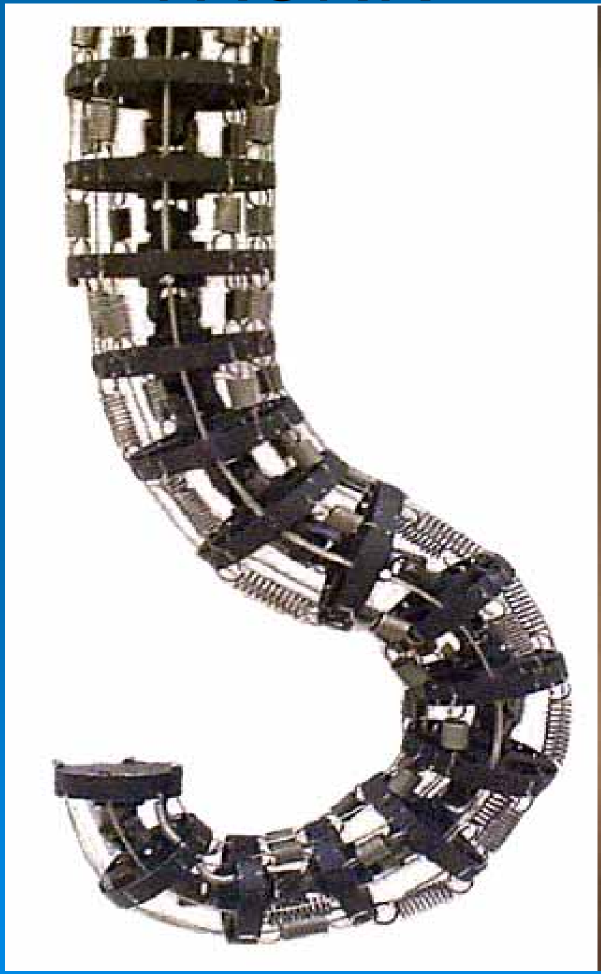
Questo movimento è stato studiato ed analizzato attraverso sequenze di immagini in cui è stata ripresa la reazione dei soggetti alla deposizione di cibo su una qualsiasi porzione del tentacolo. Le ventose dell'animale afferrano rapidamente il cibo e vengono generate **due curvature**: **una a livello distale** e una a **livello mediale**, mentre la base del tentacolo funge da **terzo "giunto" (prossimale).** La posizione del cibo ed i giunti formati definiscono, quindi, una struttura quasi-articolata che ruotando principalmente attorno all'asse mediale avvicina la parte distale alla testa.





ROBOTS

ELEPHANT TRUNK



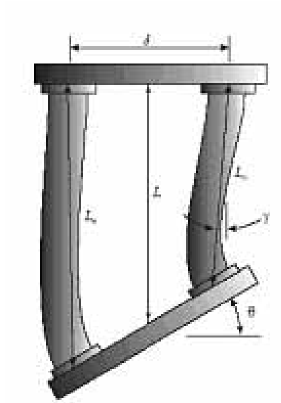
OCTARM

SNAKE

DARPA OCTARM

Si tratta di un “**Continuum Robot**”, un arto robotico con una struttura centrale continua e con mobilità omnidirezionale, in contrasto con i tradizionali robot a link rigidi. Comandato da un’apposita interfaccia software, OCTARM si muove grazie ad un **impianto pneumatico** ad aria compressa.

È composto di **4 sezioni**, intervallate e legate da **5 supporti discali** che forniscono un punto di presa per gli attuatori. In ogni sezione sono inseriti **3** attuatori **McKibben** che gli conferiscono, quindi un totale di **12 gradi di libertà**. La sua forma snodata gli permette di avvinghiarsi agli oggetti: un operatore può così controllare i movimenti del braccio robotico grazie ad una **telecamera** posizionata sull’estremità dell’arto, aiutandosi per mezzo del feedback proveniente dai **sensori tattili** che ricoprono la struttura del tentacolo.



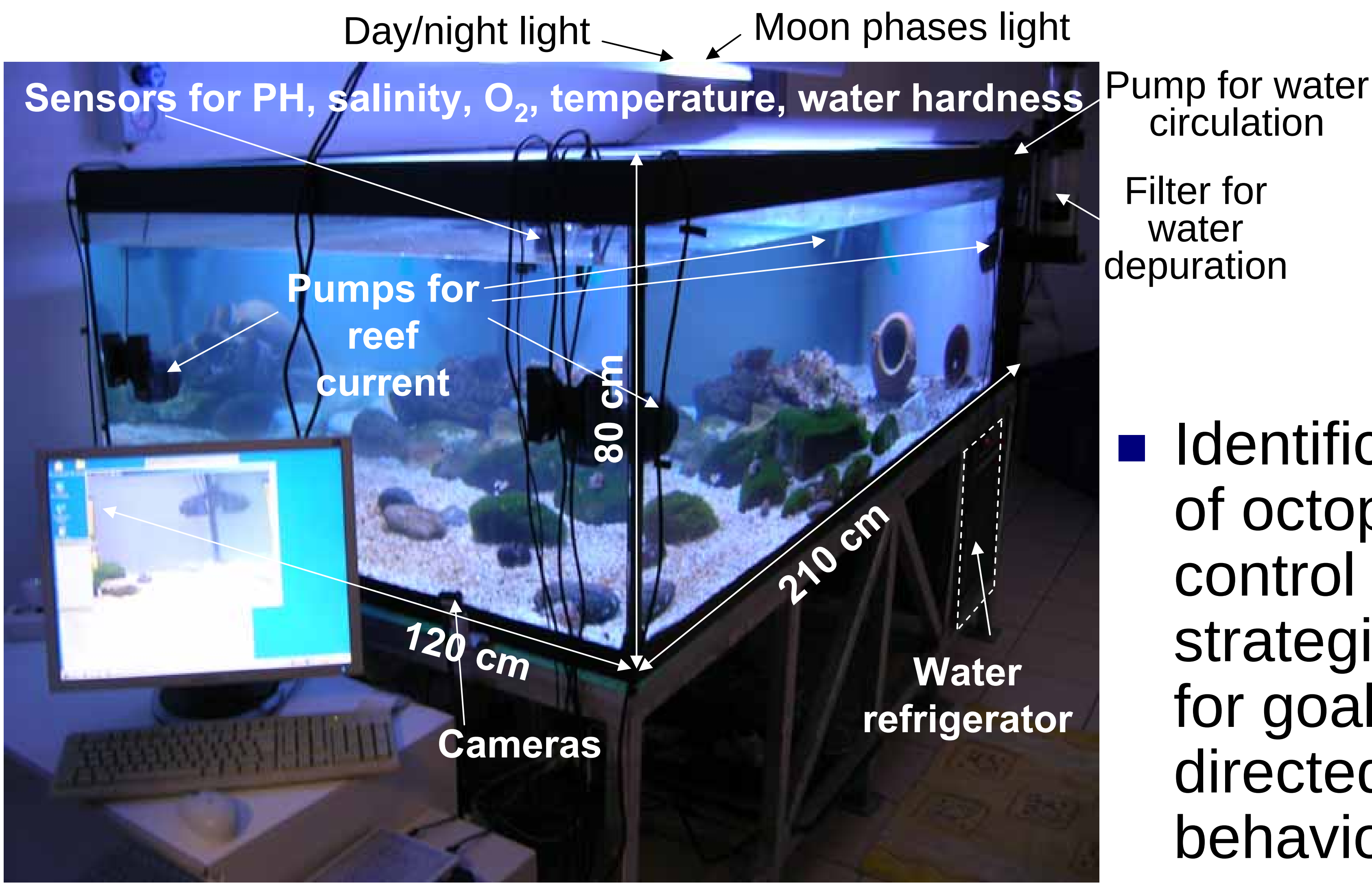
Elephant trunk

All'università di Clemson è stato sviluppato un manipolatore robotico che prende ispirazione da una struttura di un altro animale che sfrutta gli stessi principi di movimento dell'arto del polpo: la **proboscide di elefante**.

Si tratta di un modello molto più semplice di OCTARM: l'arto si curva **in sezioni con curvatura costante** ed è incapace di **torsione**.

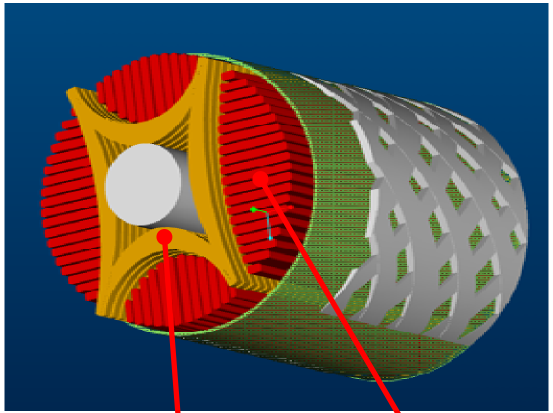
Il robot è composto di **16 sezioni cilindriche**, sottili e ravvicinate e collegate tra di loro attraverso l'uso di **giunti prismatici e rotoidali**. L'attuazione del robot prevede solo la trazione di **due cavi ogni 4 sezioni** il che implica l'uso di meccanismi di sottoattuazione per tutte le altre sezioni. I gradi di libertà totali sono **32**, di cui, quindi, solo **8 attivi**. Coppie agonista-antagonista sono formate da diverse molle di richiamo disposte in posizione diametralmente opposta ai cavi.

Ongoing work: observations of living animal



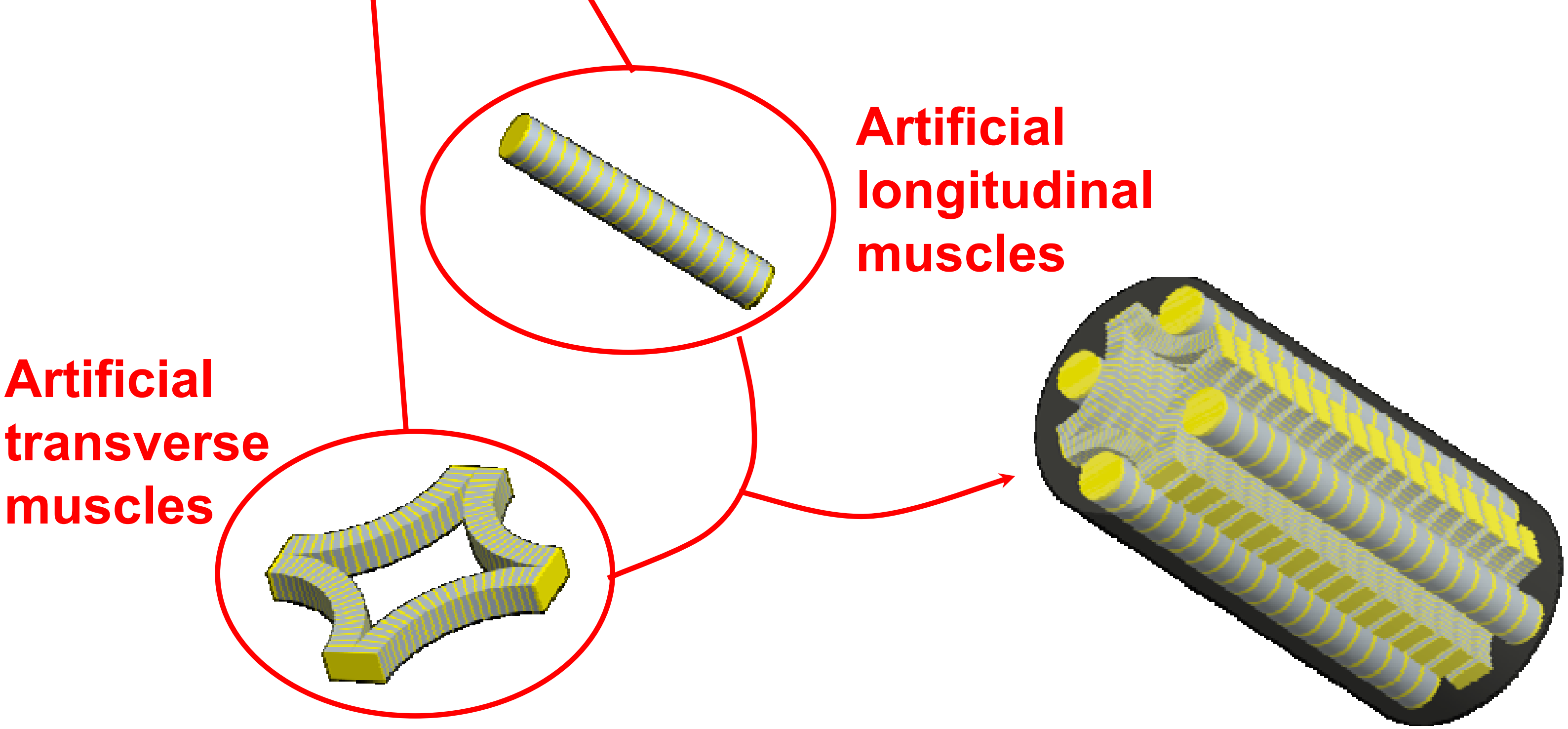
- Identification of octopus control strategies for goal-directed behavior

Design of the robotic octopus-like arm

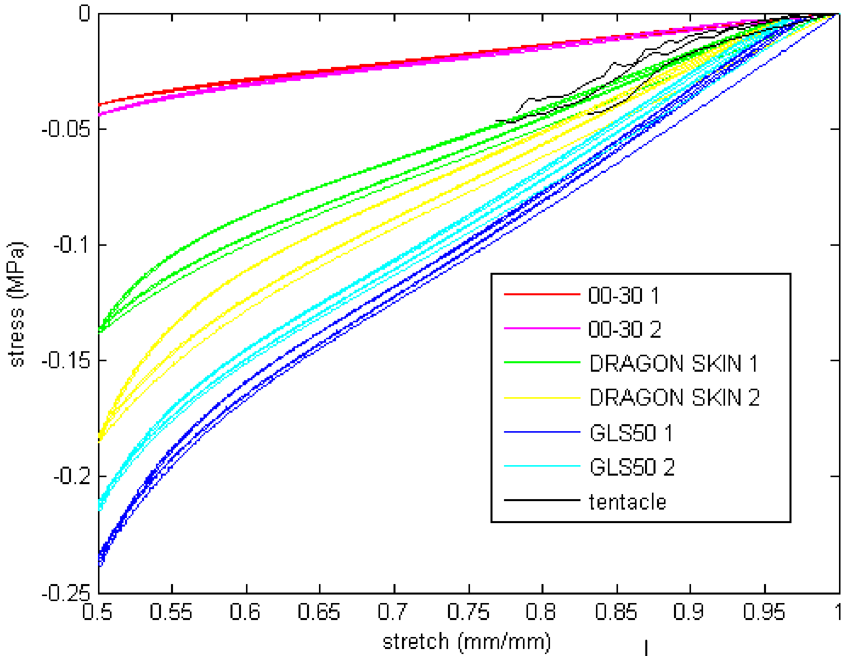


Requirements:

- -a **material compliant** enough to passively elongate as much as the octopus muscular tissue
- -an **actuator** to allow contraction of the artificial muscles

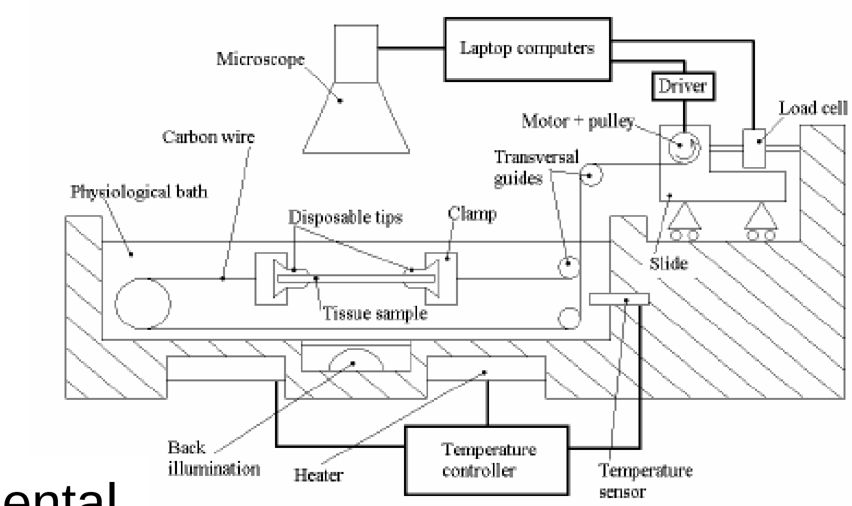


Material characterization



Experimental measurements of stress – stretch curves

Natural tentacle

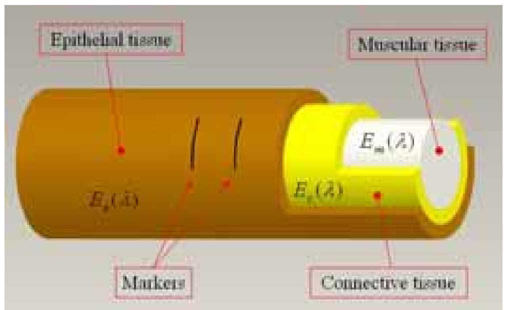


Silicones

Instron

L=2 cm
D=2 cm

Experimental setup

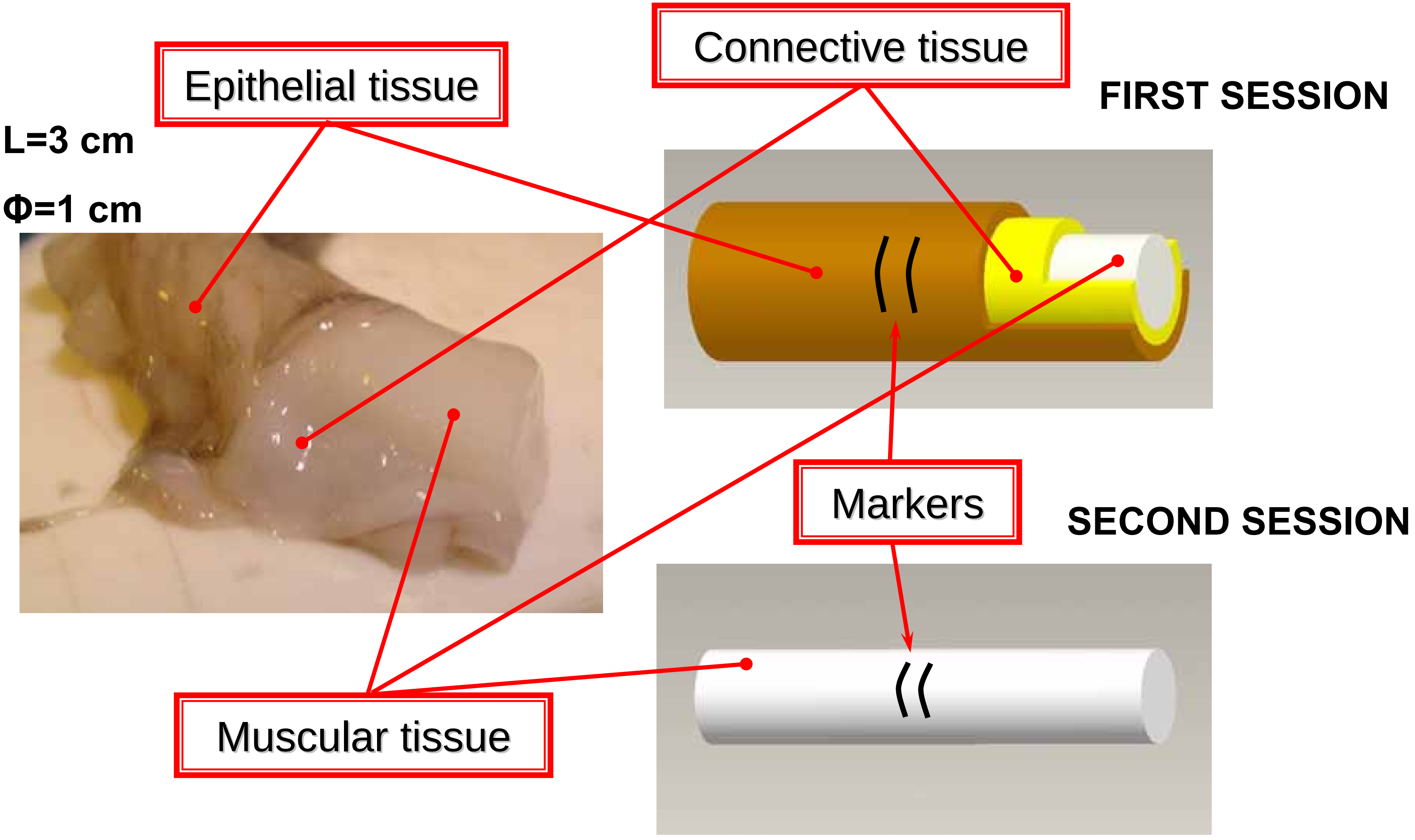


Elastic module of interpolating curves

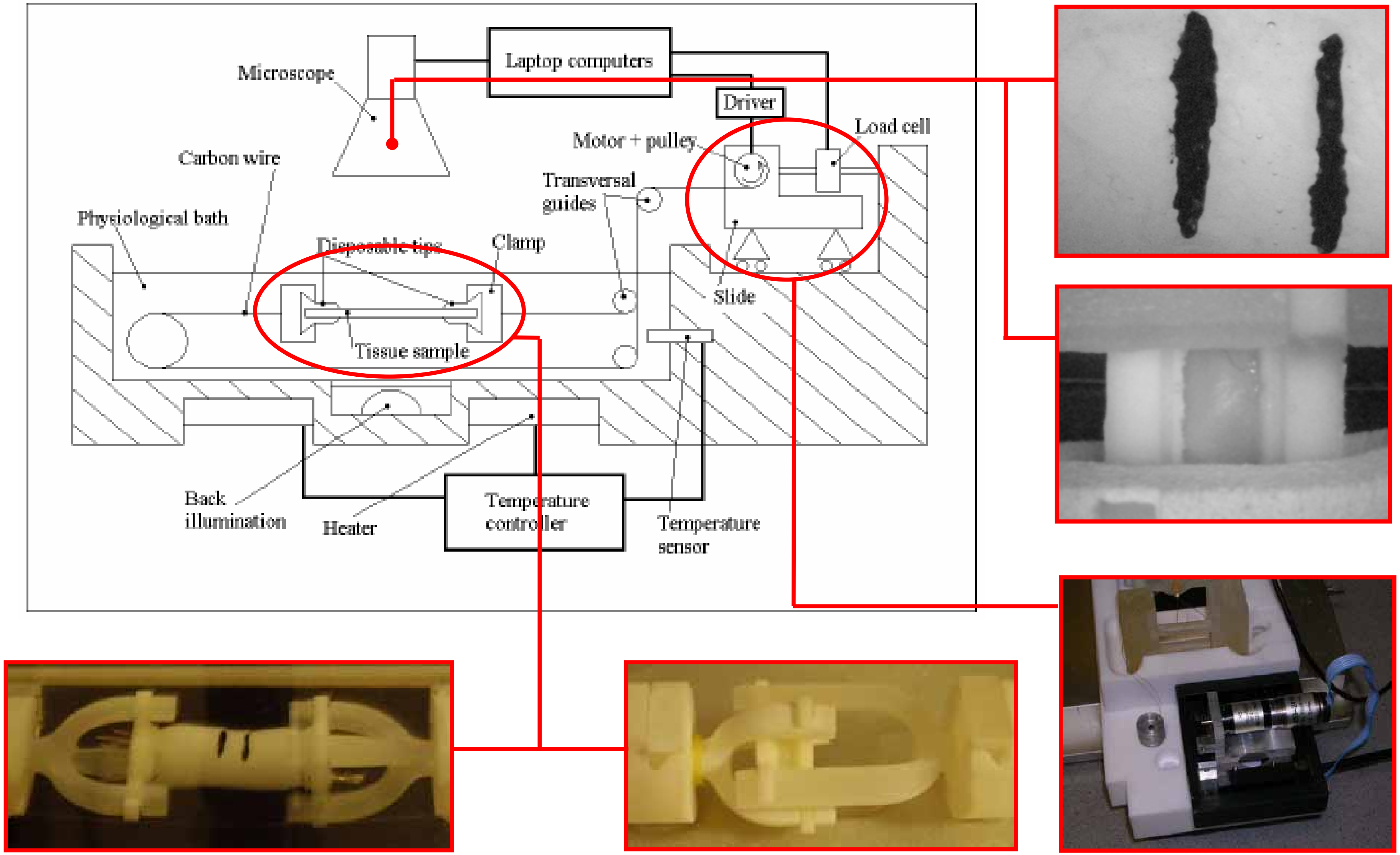
	p1	p2	p3	p4	arsquare	rmse
fit1	2,64	-7,65	7,441	-2,436	0,99114	0,0022
fit2	2,533	-7,42	7,337	-2,452	0,99478	0,0016
fit3	1,819	-5,46	5,515	-1,877	0,99249	0,0019
fit4	1,774	-5,4	5,56	-1,936	0,99641	0,0013

$$E_m(\lambda) = 3 \cdot p1 \cdot \lambda^2 + 2 \cdot p2 \cdot \lambda + p3$$

Mechanical characterization of the tentacle tissue

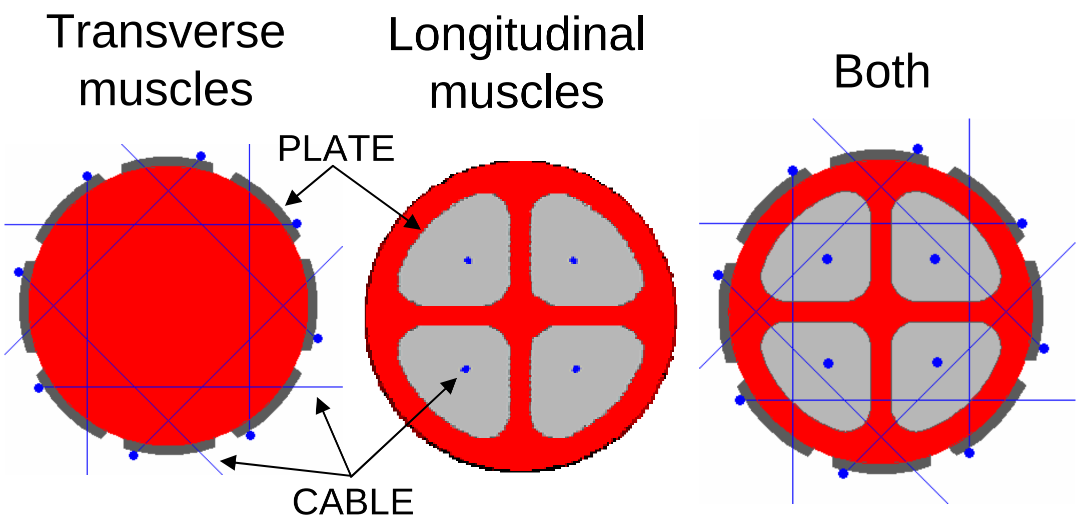


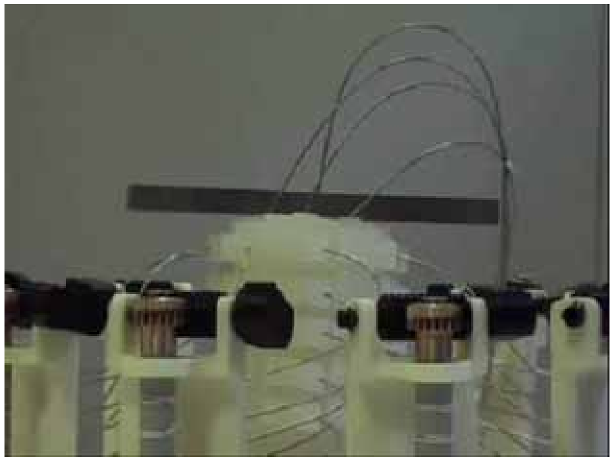
Set-up for tension/compression tests



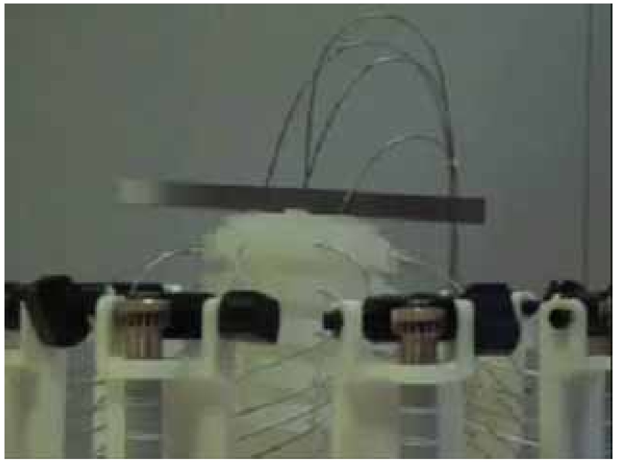
Validation of the design on a mock-up

TRANSVERSAL SECTION





ELONGATION



BENDING

Which kind of actuator is suitable?

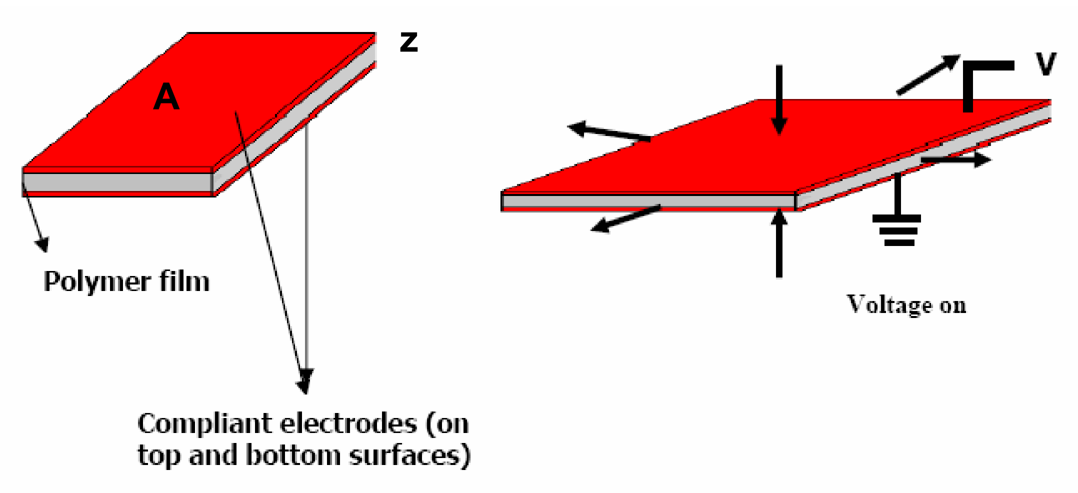
Requirements:

- Isovolumetric actuation
- Softness
- Suitable force
- Suitable Speed (bandwidth >1Hz)
- Suitable strain

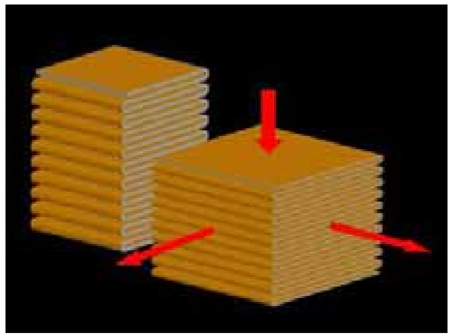
Design of an actuator for the robotic muscles (ElectroActive Polymer – EAP)

- Soft materials
- Passive deformation capability
- Relatively ‘fast’ response time

Dielectric elastomers are a type of EAP that uses an electric field across a rubbery dielectric with compliant electrodes.



$$F = -\frac{dU}{dz} = \frac{\varepsilon_r \varepsilon_0 V^2}{z^2} A$$



Actuator design

ELECTRODE CHOICE

Requirements:

- Good Conductivity
- Compliance
- Stability / Reliability

Possible candidates:

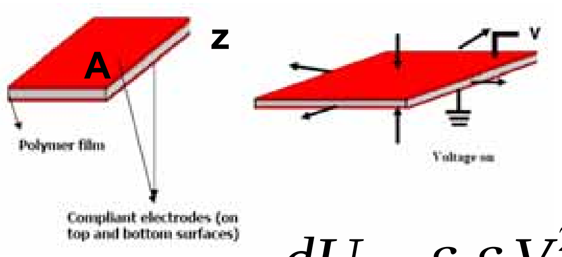
- Graphite embedded in a silicon matrix
- Graphite Spray
- Thin Gold Film

→

- Sputtering Deposition
- Pre-stretch of substrate makes the deposited film compliant

Design of an actuator for the robotic muscles (ElectroActive Polymer – EAP)

- Soft materials
- Passive deformation capability
- Relatively 'fast' response time



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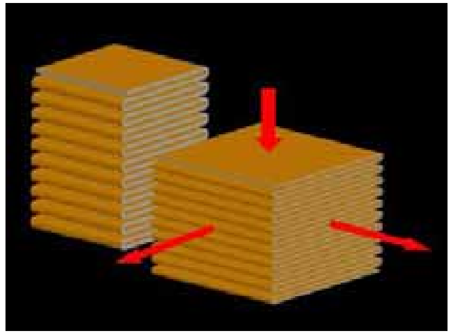
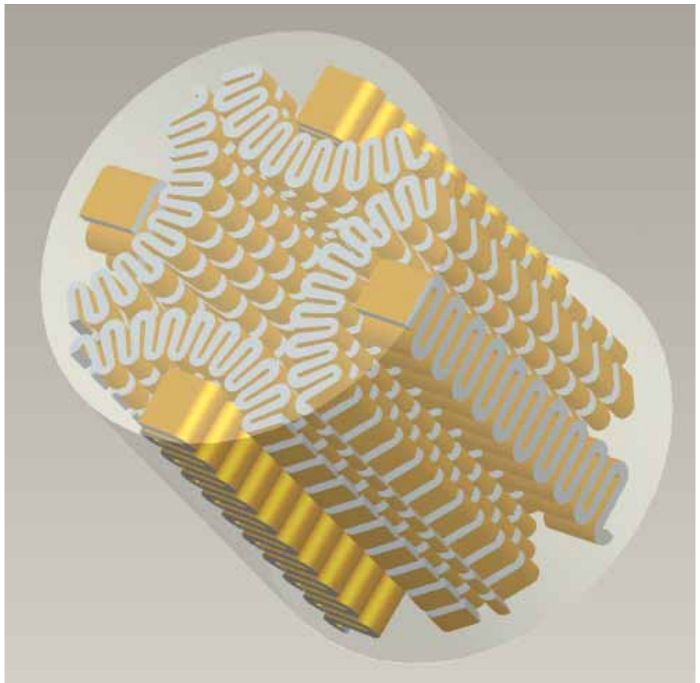
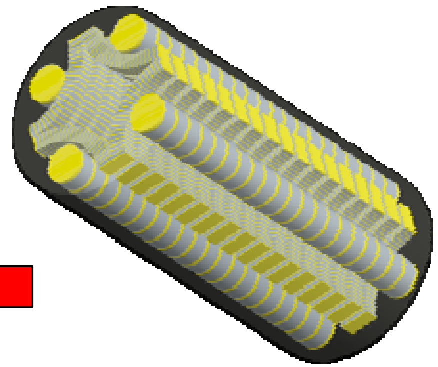
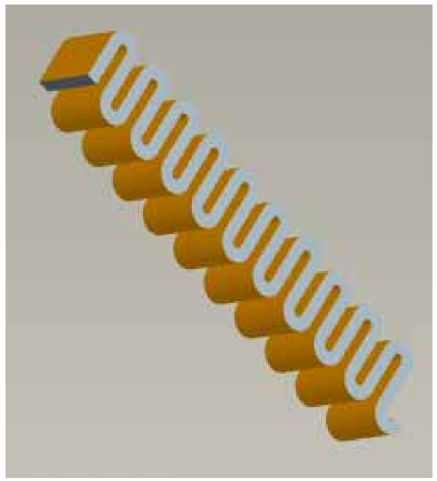


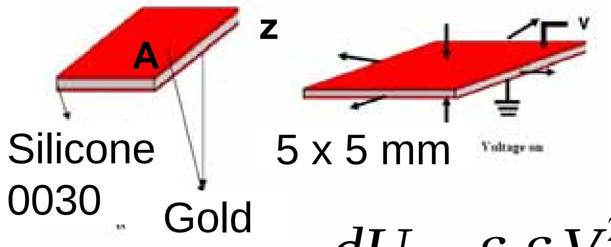




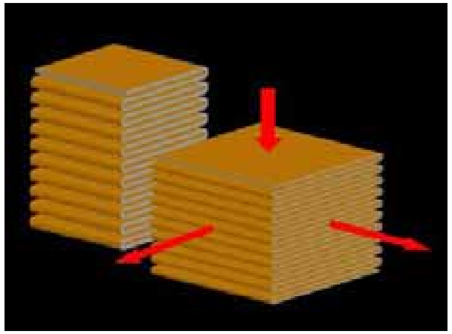


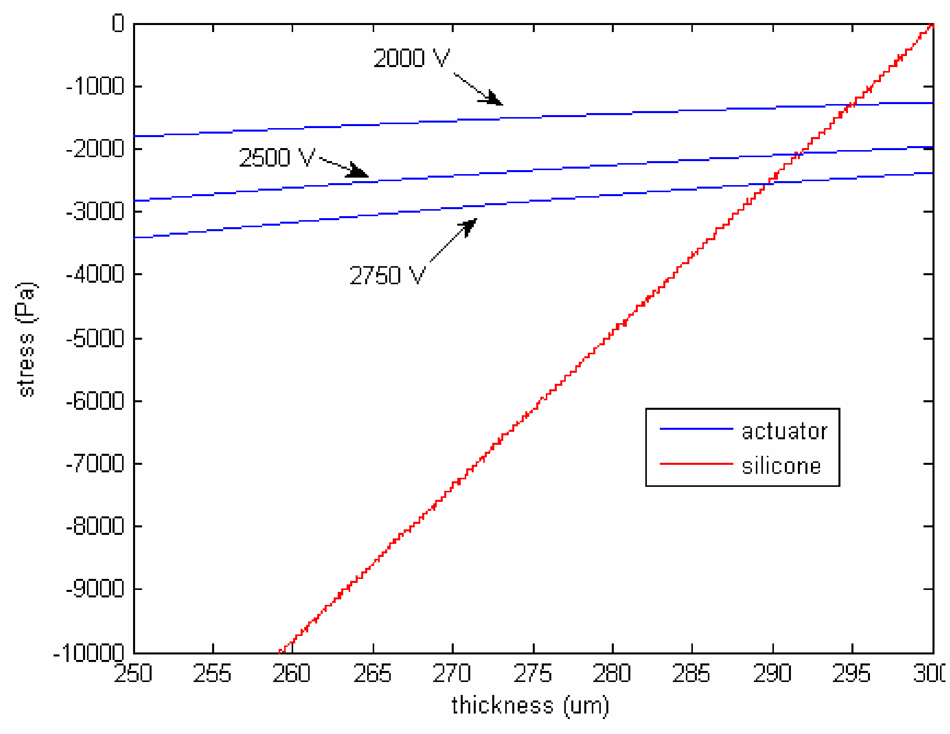
Design of an actuator for the robotic muscles (ElectroActive Polymer – EAP)

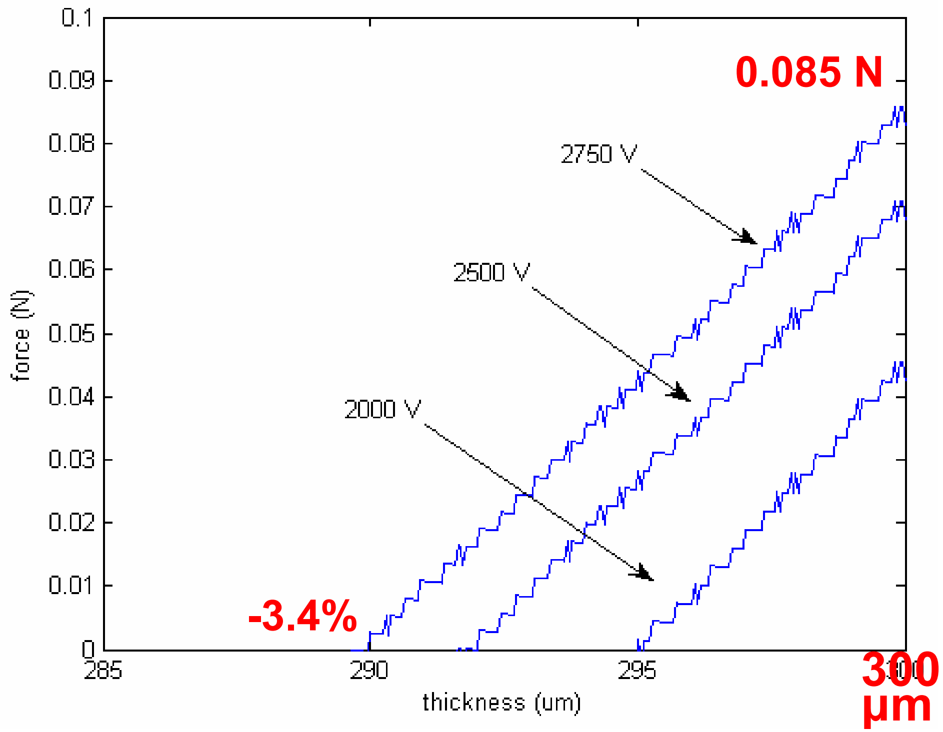
- Soft materials
- Passive deformation capability
- Relatively 'fast' response time



$$F = -\frac{dU}{dz} = \frac{\varepsilon_r \varepsilon_0 V^2}{z^2} A$$

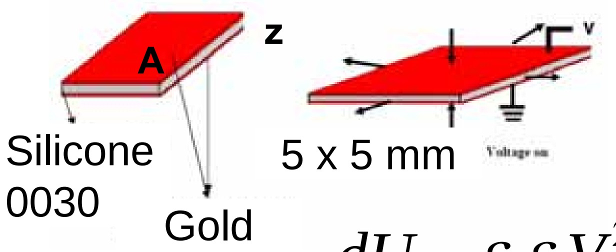




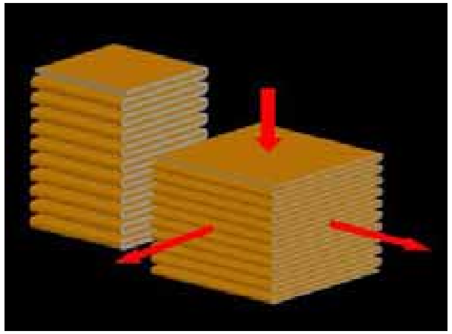


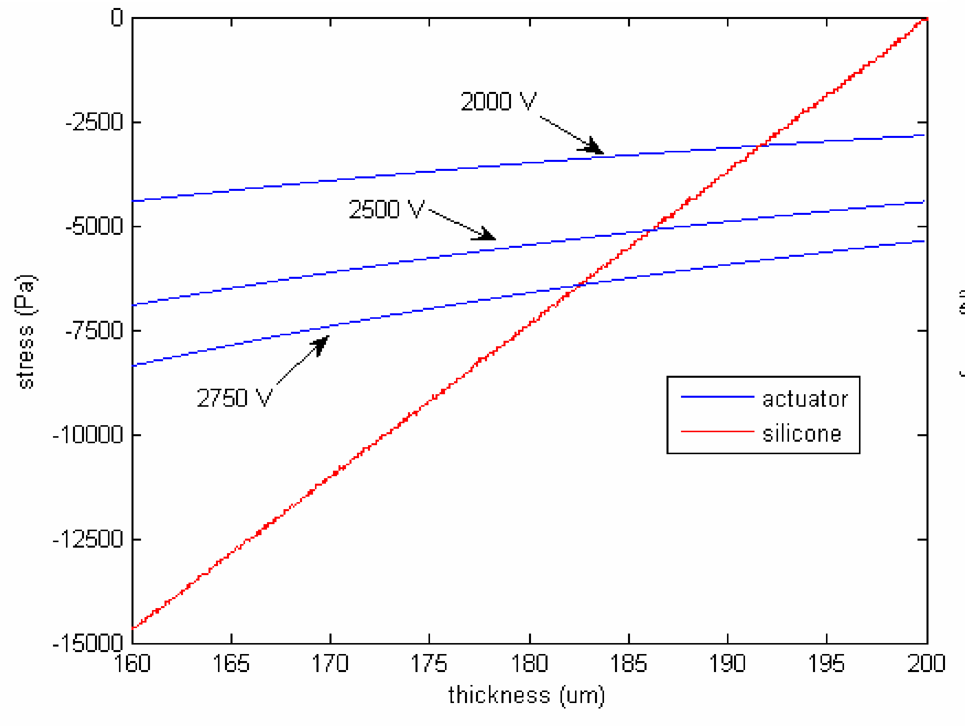
Design of an actuator for the robotic muscles (ElectroActive Polymer – EAP)

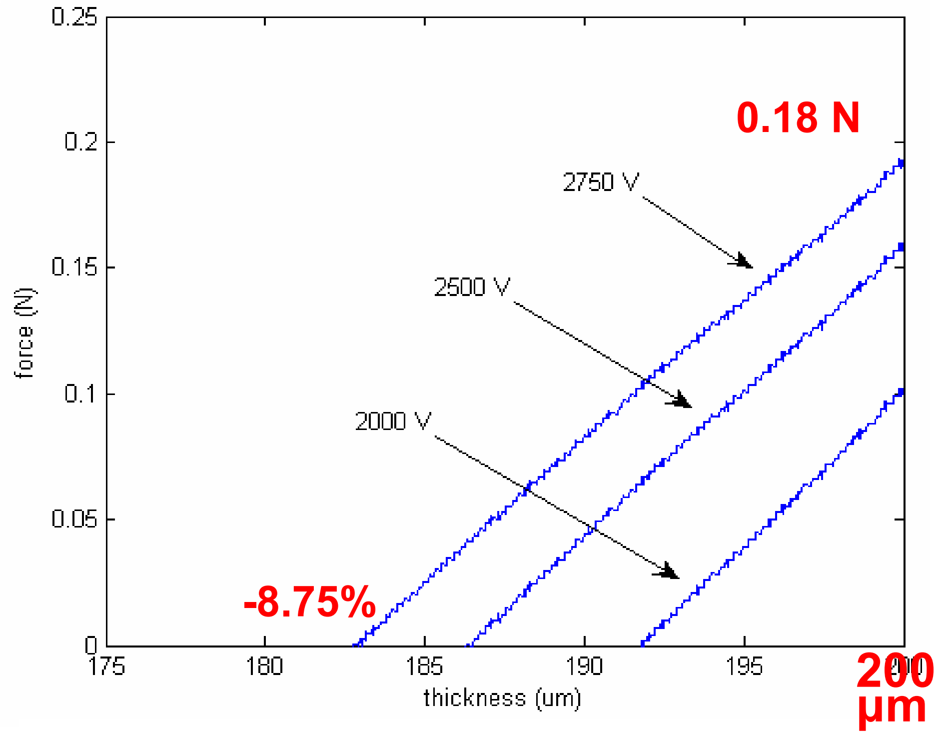
- Soft materials
- Passive deformation capability
- Relatively ‘fast’ response time



$$F = -\frac{dU}{dz} = \frac{\varepsilon_r \varepsilon_0 V^2}{z^2} A$$







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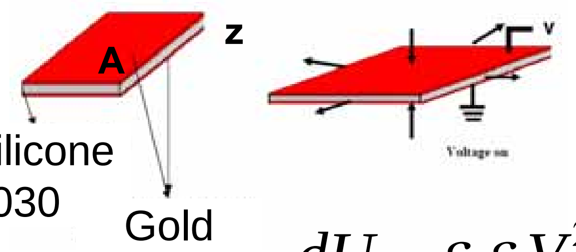

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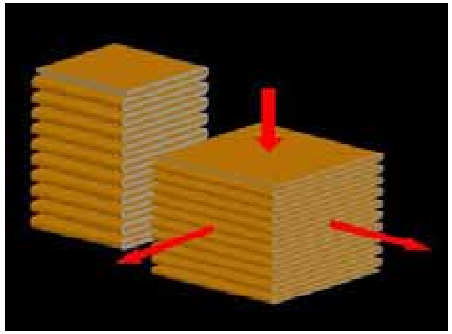
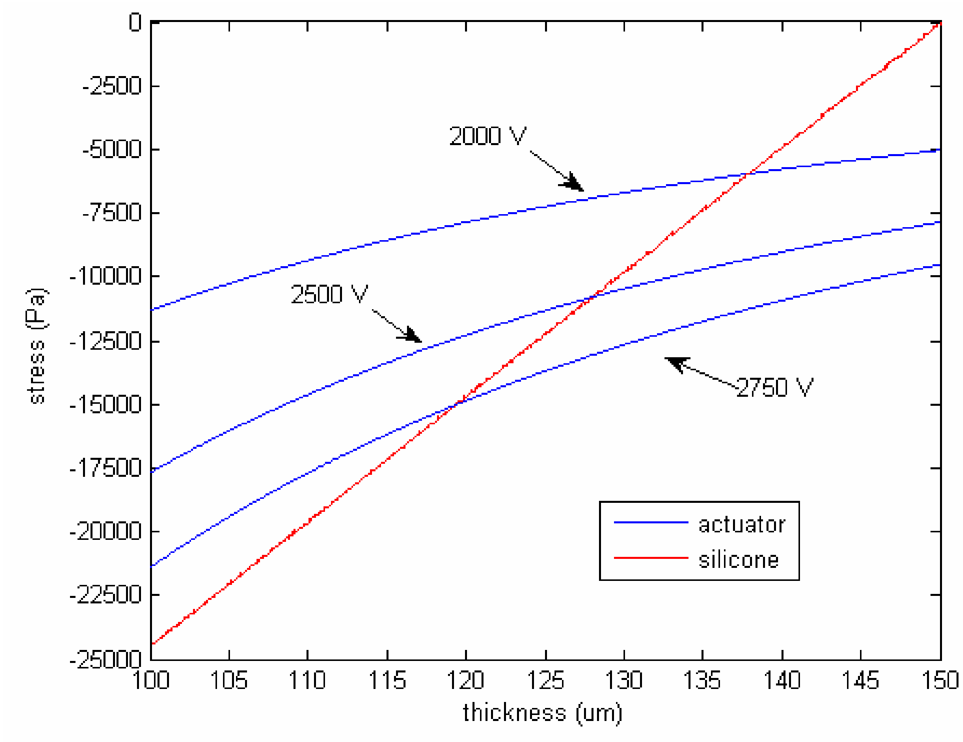
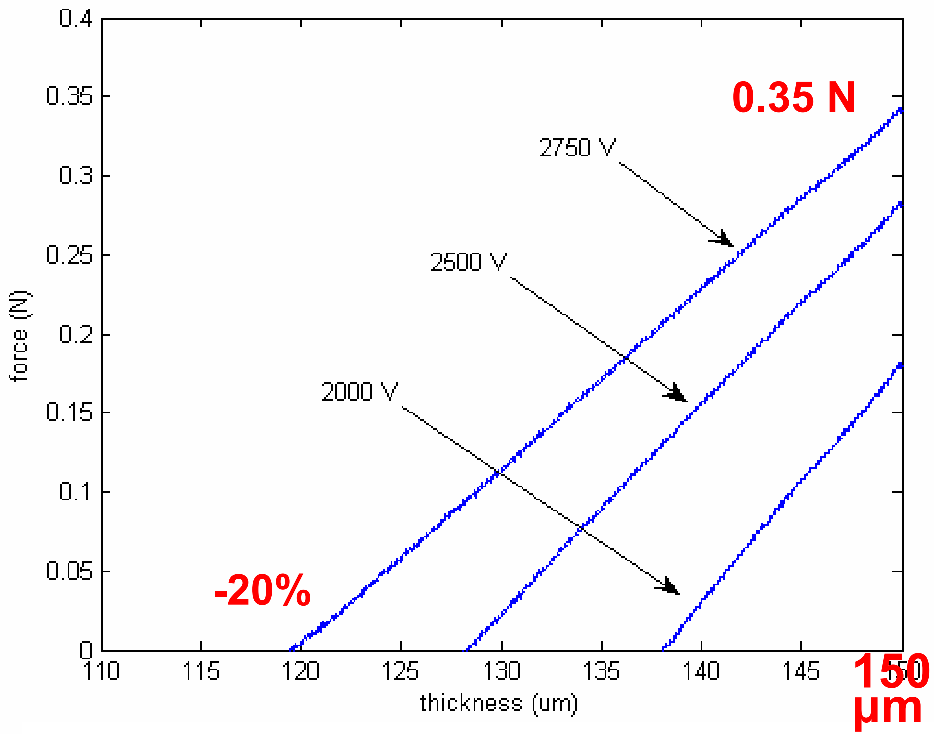
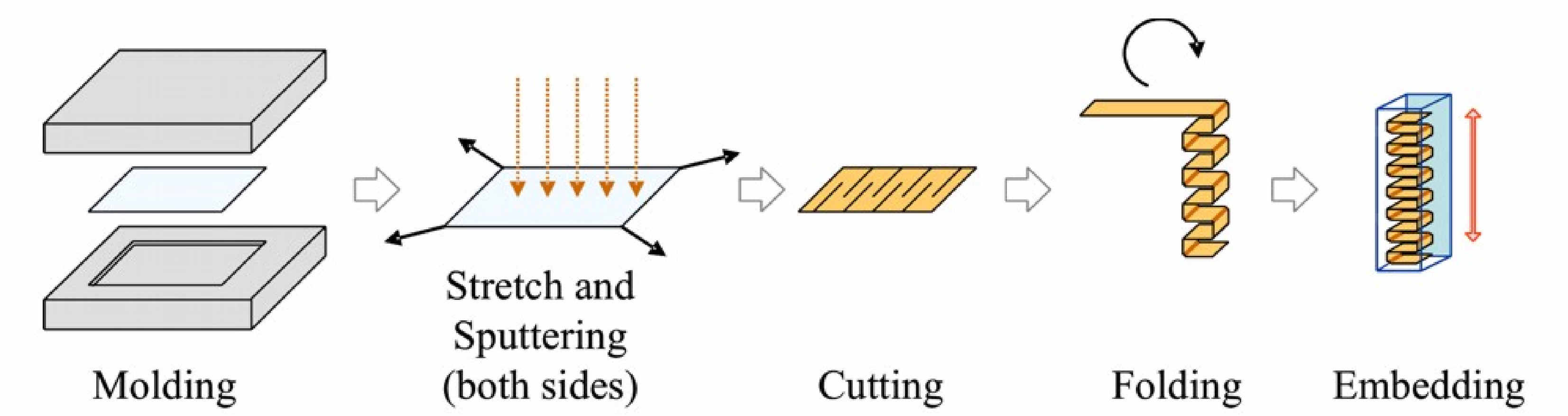






Fabrication of the EAP actuator



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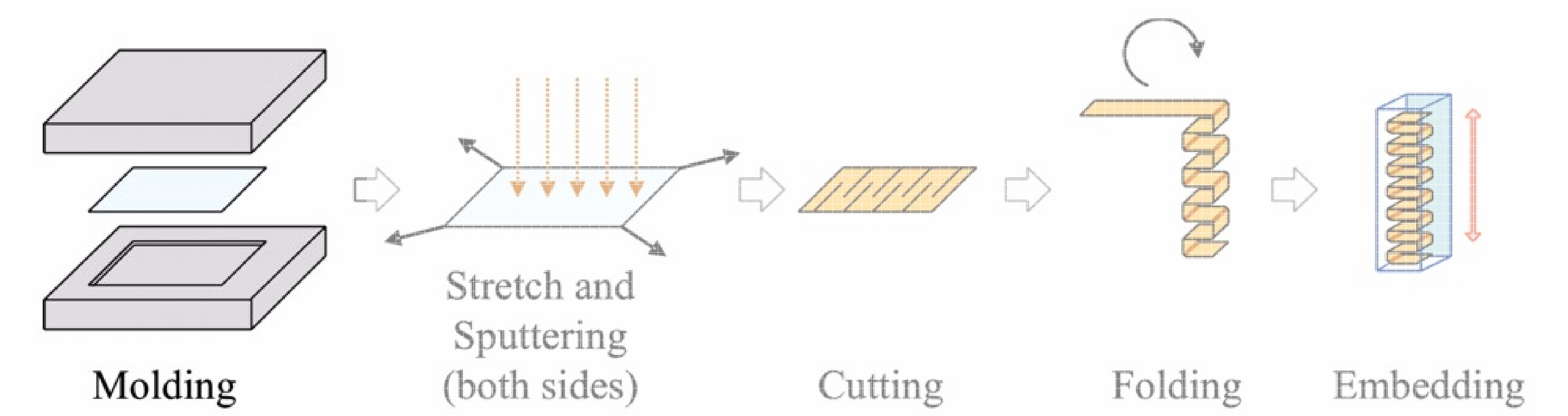
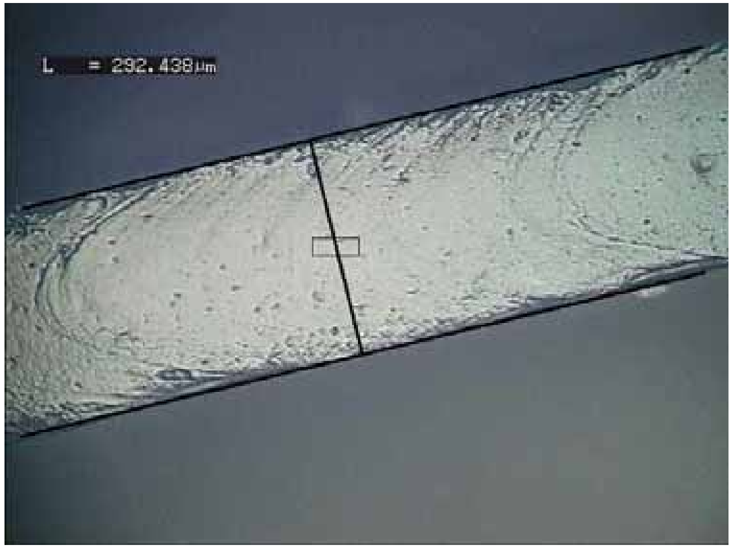
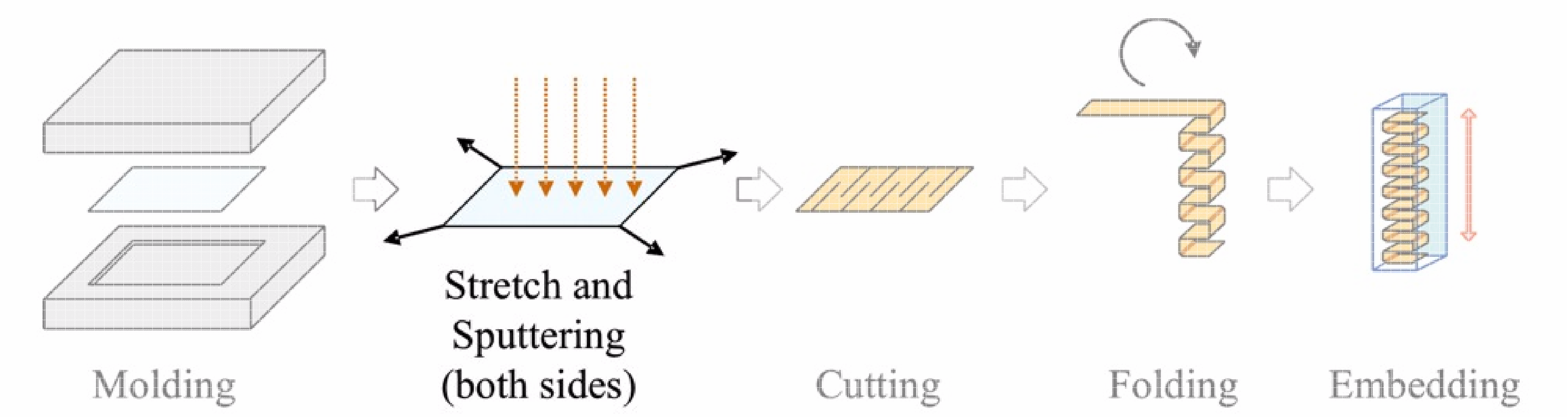


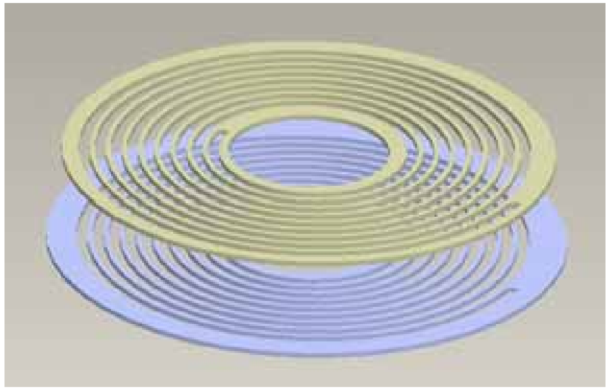


It is possible to obtain very thin silicone films with high surface control

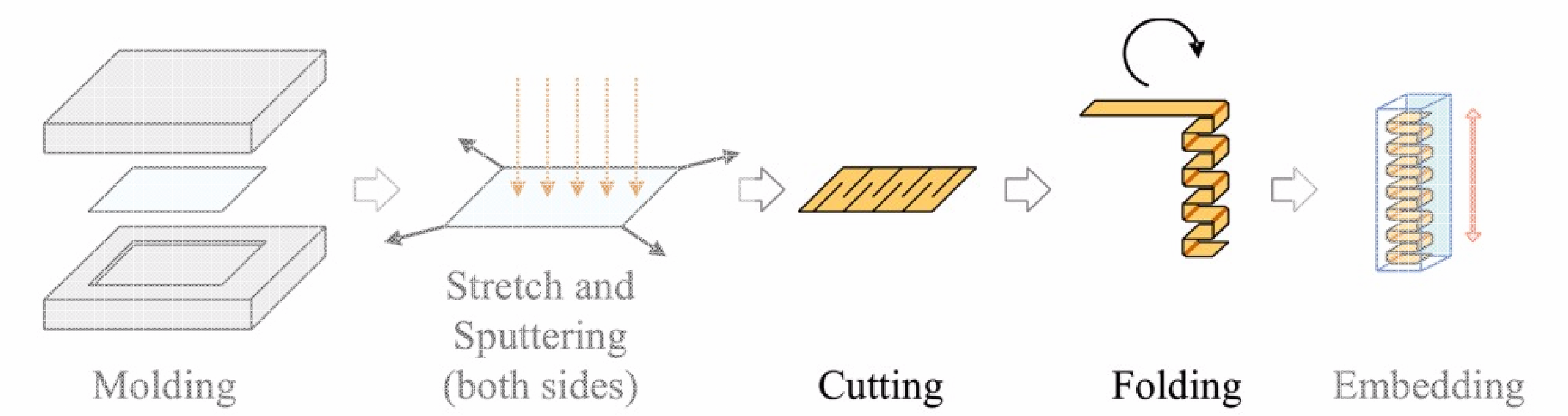
Fabrication of the EAP actuator



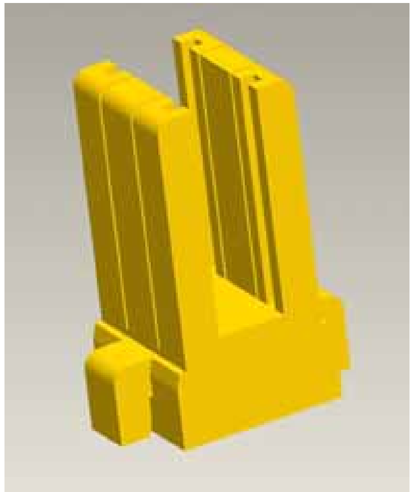
The stretched silicone film is fixed inside a double spiral mask and then **sputtered with gold** on both side

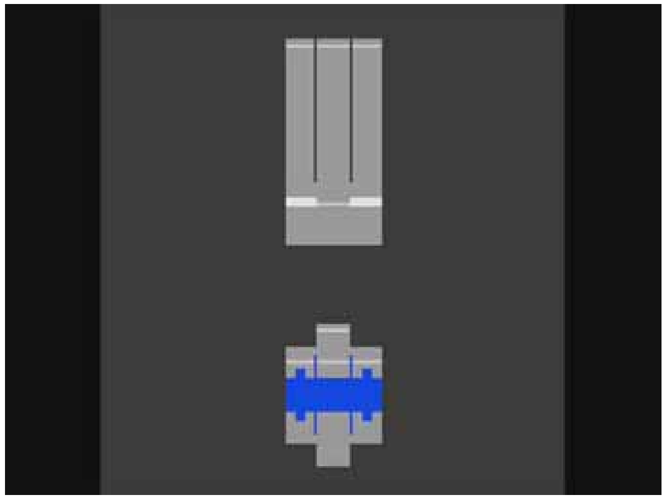


Fabrication of the EAP actuator

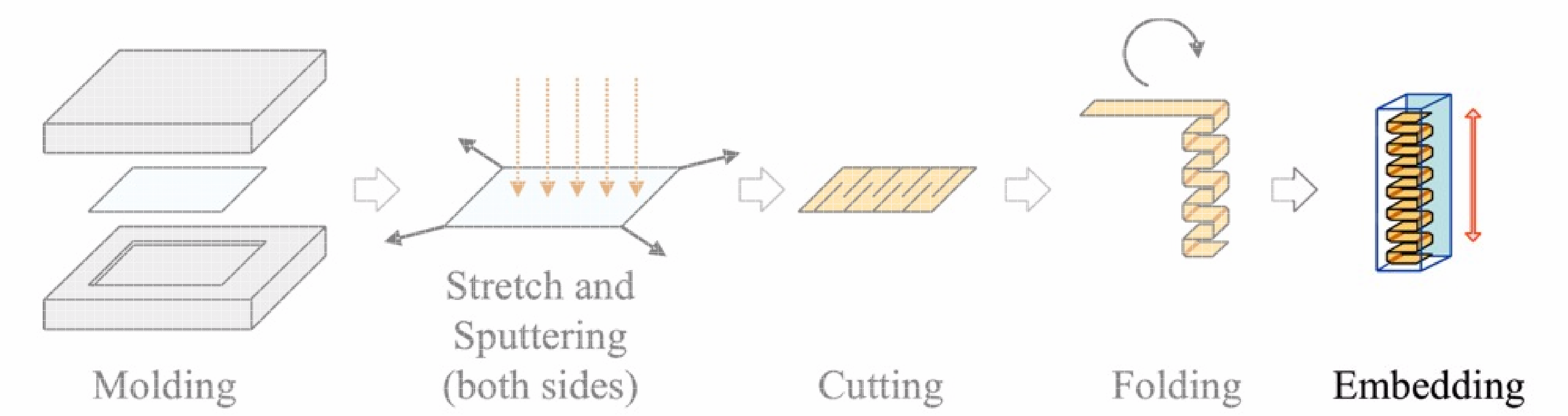


The sputtered silicone film is detached from the masks and cutted. The stack is built by folding the sputtered film using a castle-like structure (fabricated by a 3D printer)





Fabrication of the EAP actuator



A little quantity of silicone is used to maintain the folded film and to fix every layer with the nearest one