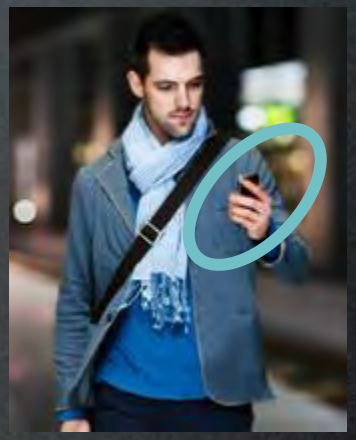
Revolutionizing Mechatronics

How
Rapid Robot Prototyping
and
Open Source Design
are changing Robotics

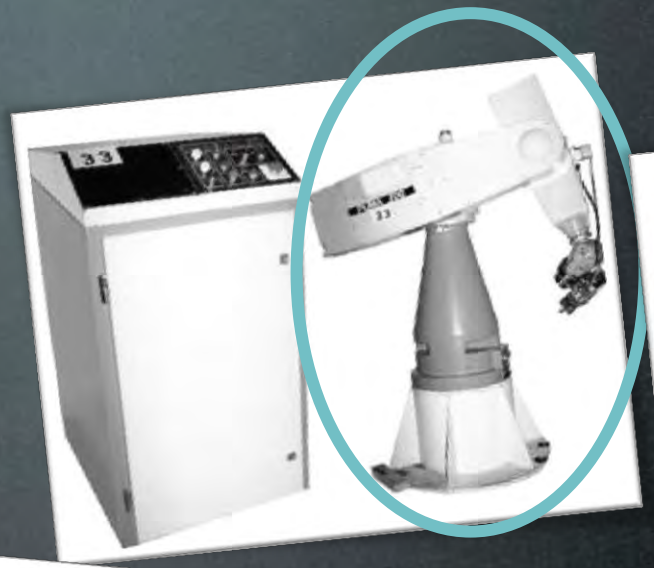
Machine Intelligence

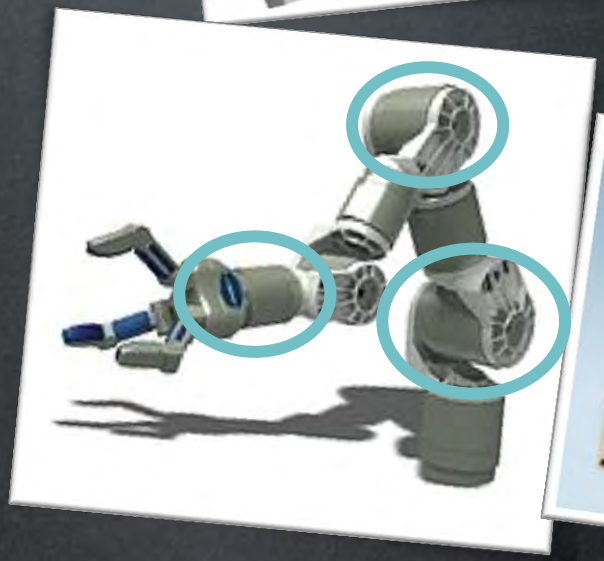
- Yesterday: Puma
  - Motorola 68K
  - 8 MHz
  - 160 Kflops
- Today: smartphones
  - Snapdragon S4
  - 1.5 GHz
  - 6.4 Gflops



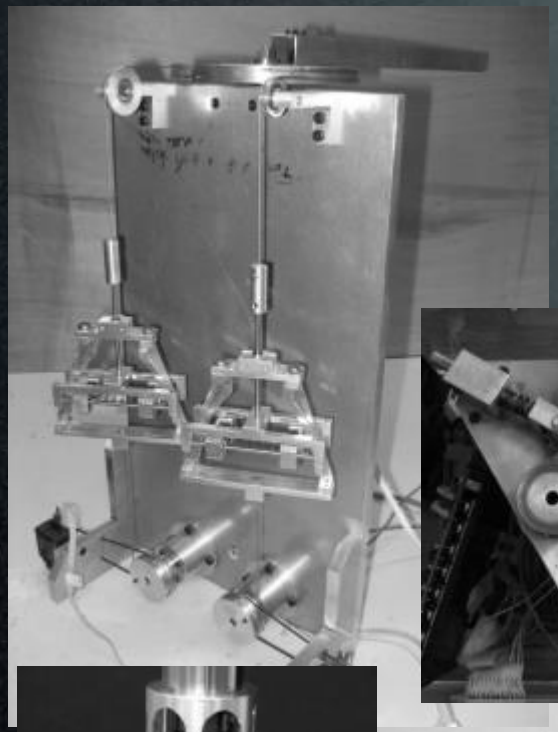
Machine Motion

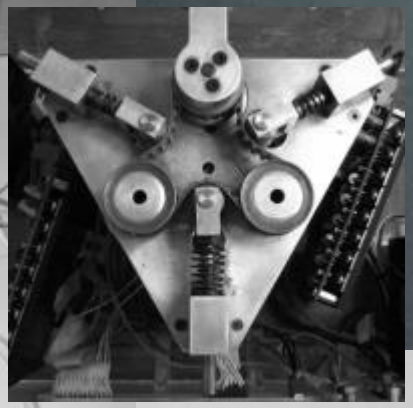
- 1960's robotics
  - Unimate Puma
  - Servomotors
- 2010's robotics
  - Servomotors

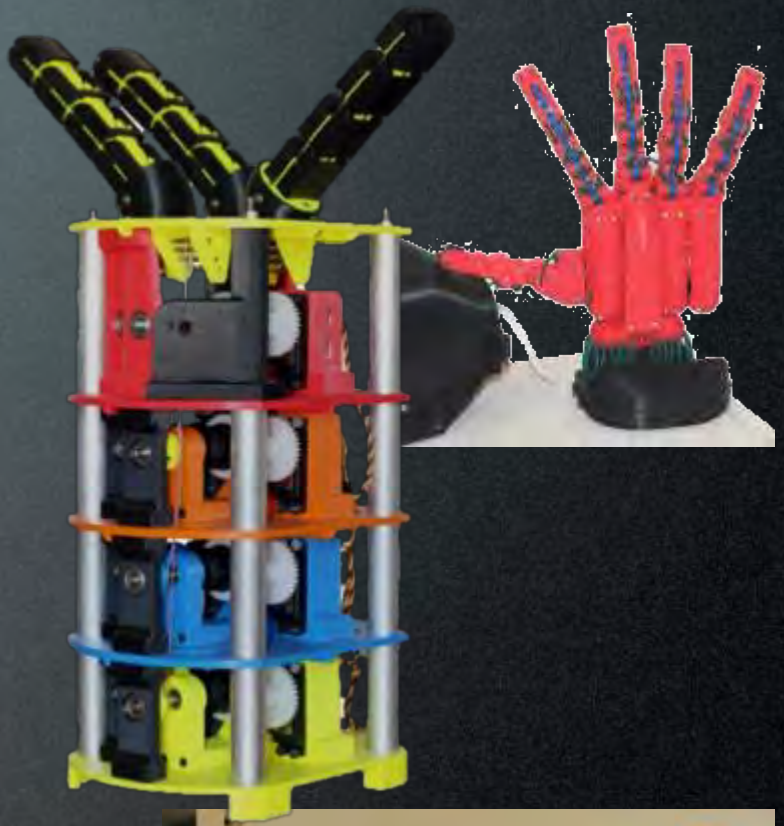




Labs are a-changing…







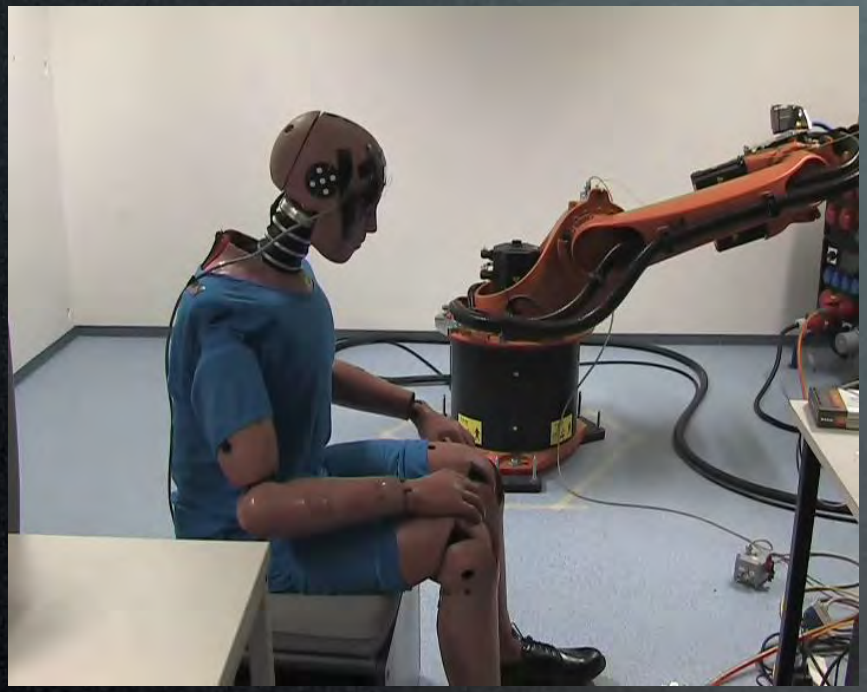
Enabling Technologies

- Additive Manufacturing

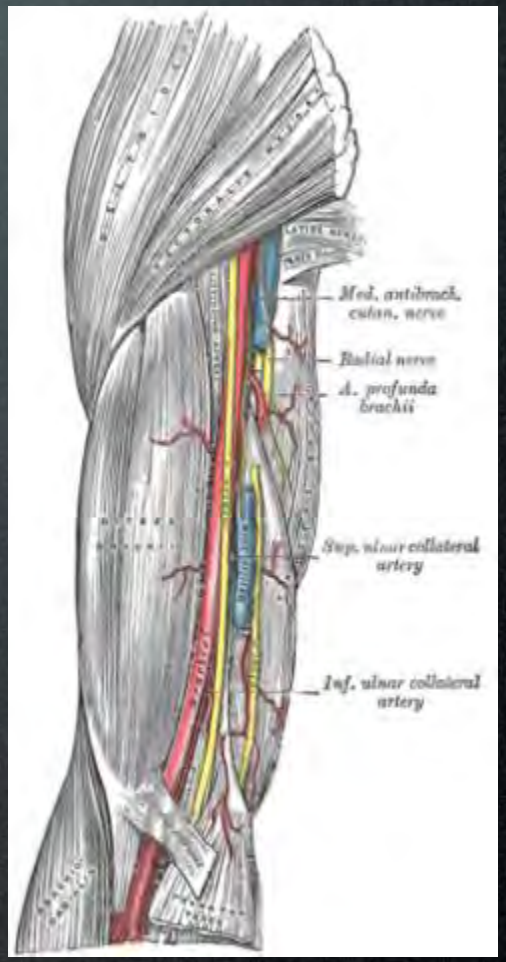
  - Stereolithography (SLA)
  - Laminated Object Manufacturing (LOM™)
  - Ink Jet (PolyJet 3D Printing)
  - Selective Laser Sintering (SLS®)
  - Fused Deposition Modeling (FDM)

- New OS embedded uControllers (e.g. Arduino)
- New Sensors (e.g. magnetic encoders)
- New HW-in-the-loop tools
- New OS SW & MW (e.g. toolboxes, ROS, Yarp)

How will robots look like in 10 years?



Certainly not like their good, old, stiff, and heavy ancestors

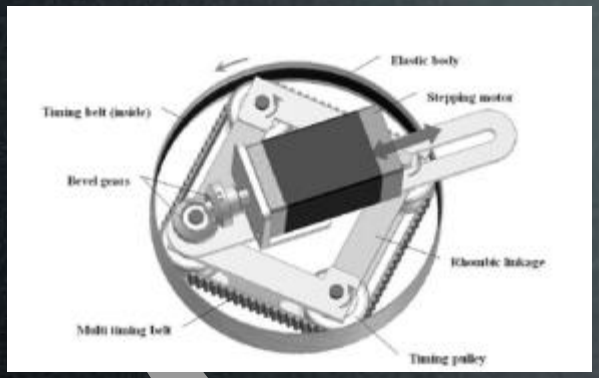


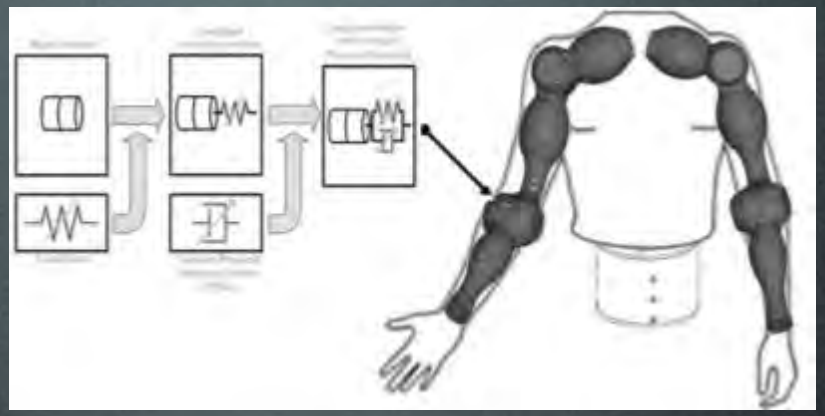
Perhaps not like this either

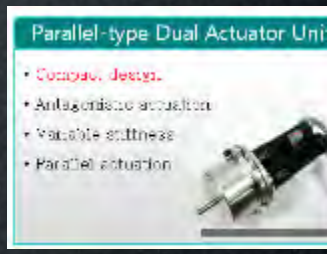
Evolution of actuation

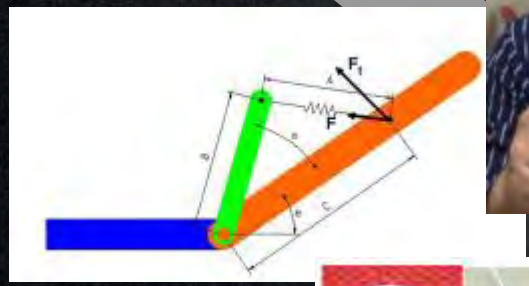
- Rigid actuation (e.g.: servomotors)
- Torque-Controlled Actuators
- Series Elastic Actuation
- Variable Stiffness and Variable Impedance Actuation

Variable Stiffness Actuators - Worldwide

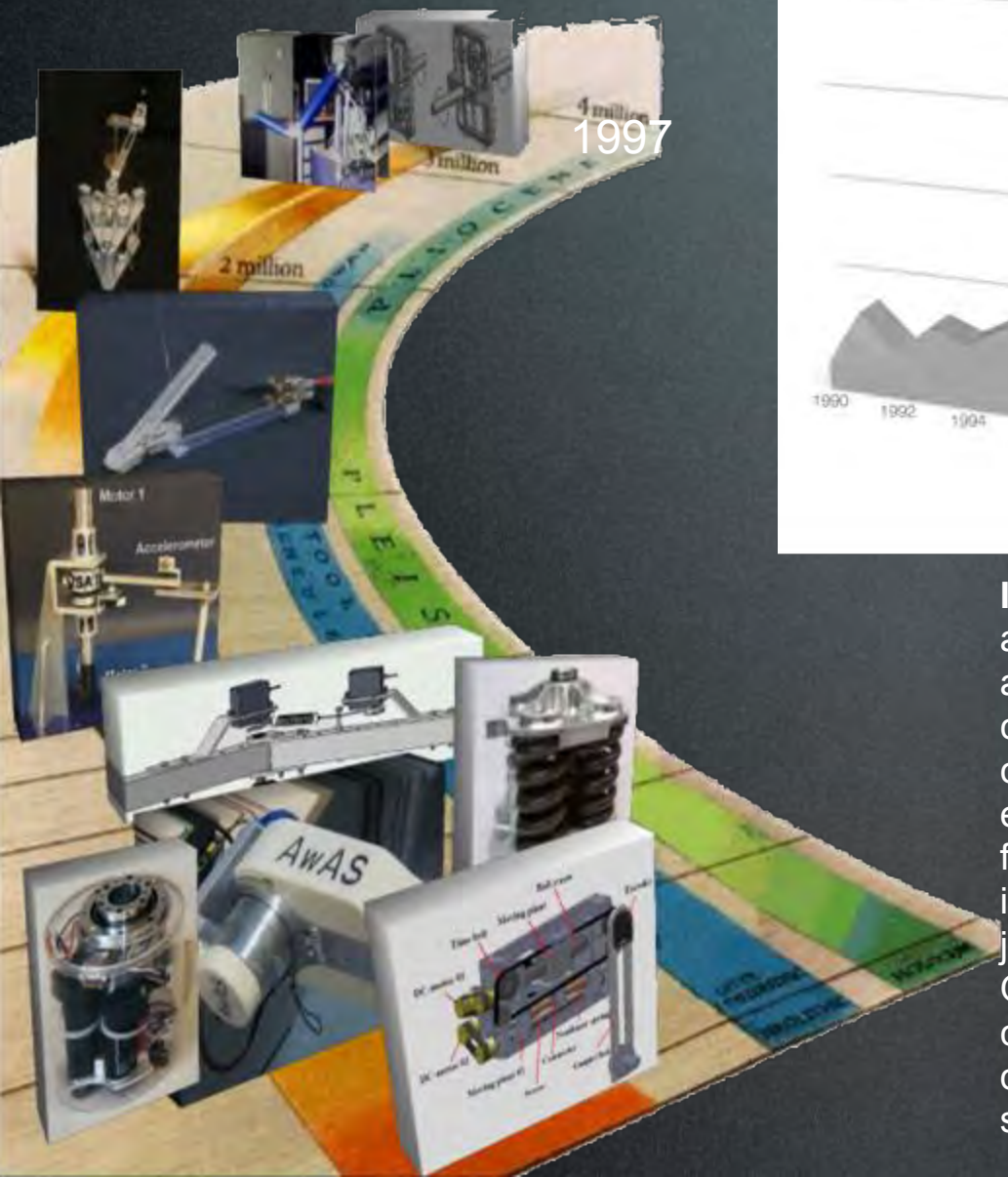


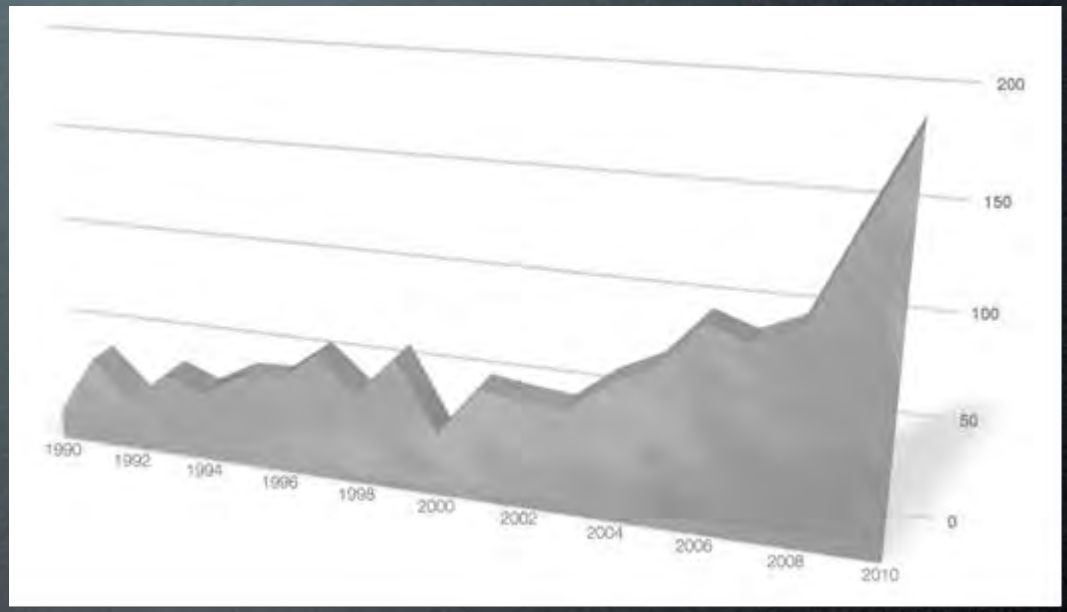






Variable Stiffness Actuators

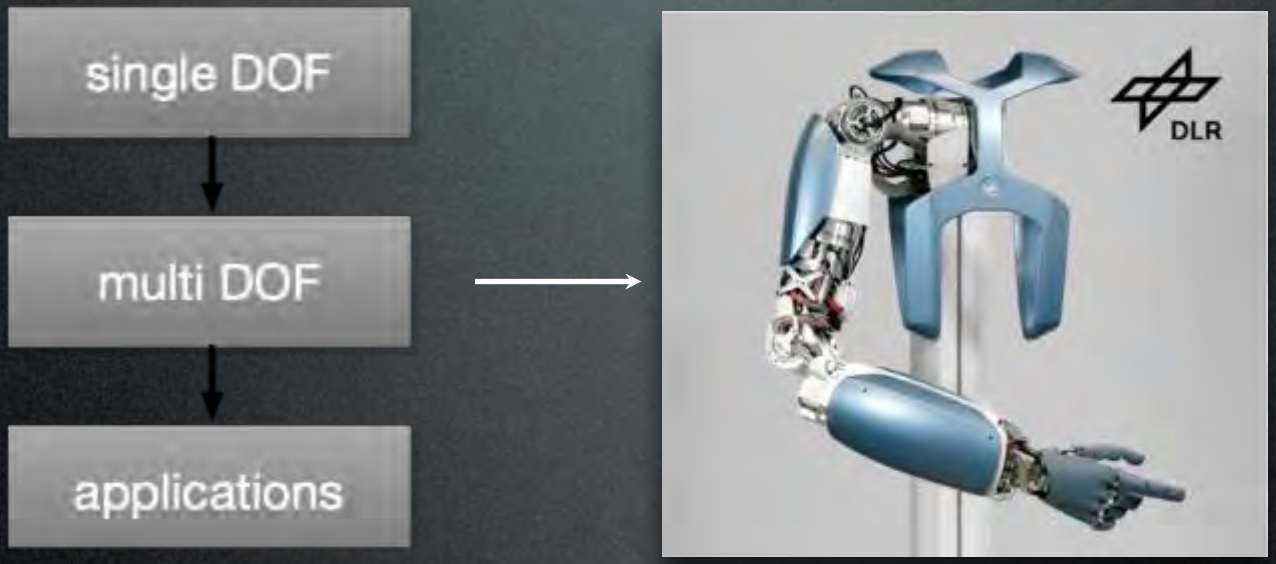




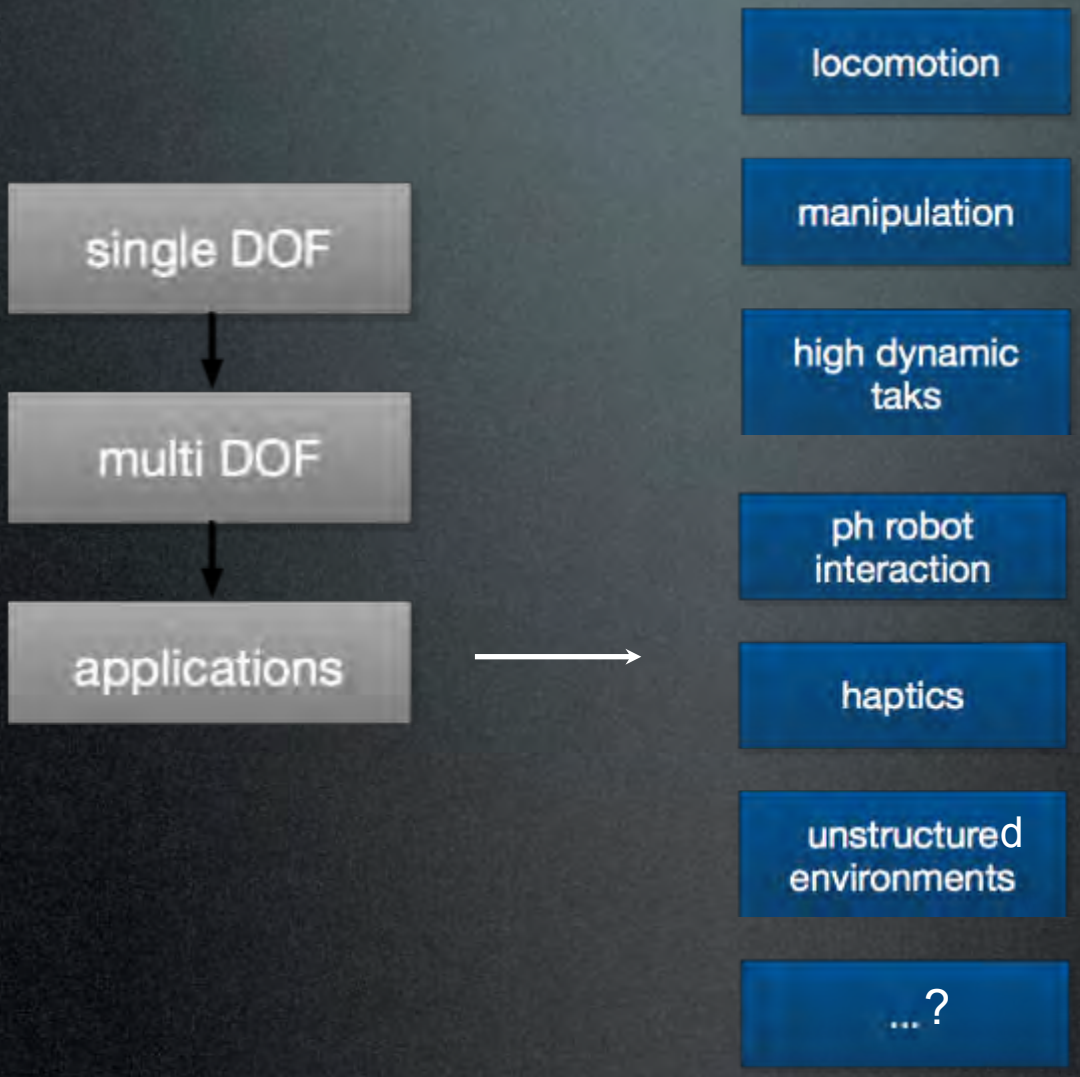
IEE Xplore Search:
active compliance OR adjustable compliance OR adjustable damping OR compliance controller OR compliant actuation OR compliant actuator OR compliant control OR compliant controller OR elastic actuation OR elastic transmission OR flexible actuation, flexible actuators OR impedance control OR impedance controller OR joint impedance OR joint stiffness OR soft robotics OR soft robot OR soft robotics OR stiffness control OR stiffness controller OR variable damping OR variable compliance OR variable stiffness actuator.

Applications of VSA & VIA

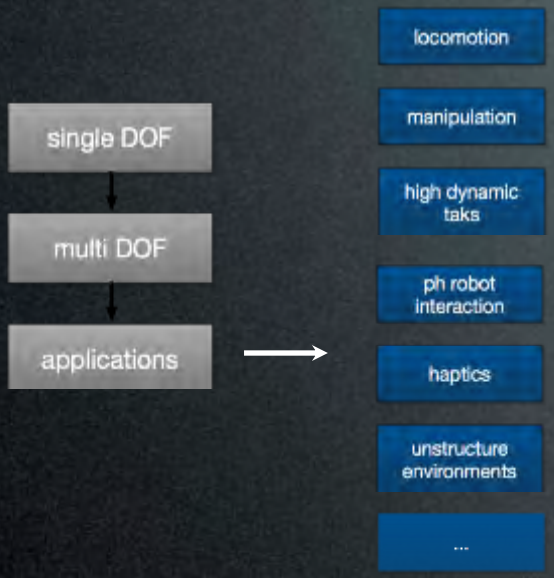
Applications of VSA & VIA



Applications of VSA & VIA



Applications of VSA & VIA



- We suspect there is a much wider range of applications than few researchers alone can explore
- Idea:
  crowdsource the exploration of new territories

natural motion initiative

*an **open** initiative to foster the diffusion of **soft** actuation in **robotics***

SAPHARI

Safe and Autonomous Physical Human-Aware Robot Interaction

qb robotics

azienda spin-off
Università di Pisa

Take the Initiative

Main issues

- Cost
- Time
- Know-how
- Diffusion

Solutions

- Standard parts
- Modularity
- Public access, easy utilization
- Open discussion

Full Open Platform

- **SW**
- **Electronics HW**
- **Mechanical HW**

natural motion initiative

- open paradigm
  - BSD & Creative Commons licensing
  - leads to the fast diffusion of the technology
  - best choice for developers
  - create a community to get support and feedback
  - examples: Linux, I-Cub, Arduino

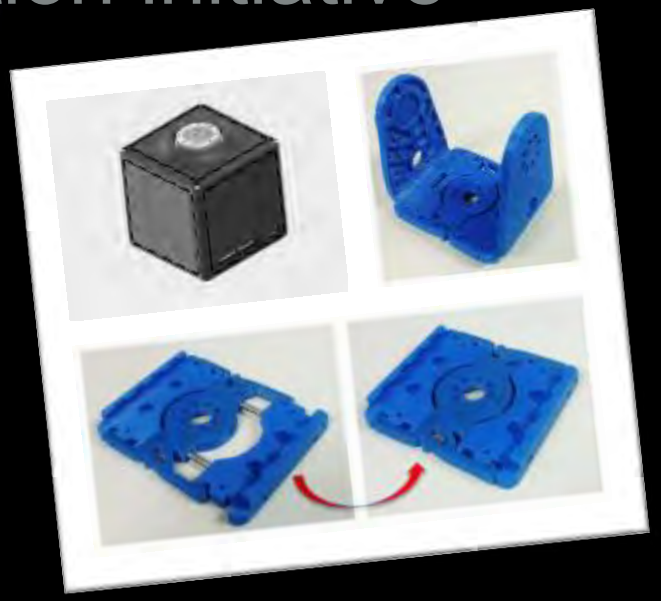
natural motion initiative

- 3 main sections

  - **Learn** – Wiki, Q&A, Forums
  - **Explore** – projects are here (as well as some photos and videos)
  - **Participate** – news, events and registration info

qbmove & qbmate

first fruits of the natural motion initiative



qbmove

- A Natural Motion™ actuator
  you can download and build yourself

qbmove

- A Natural Motion™ actuator
  you can download and build yourself
- Three versions:
  - Maker
    - nominal torque of 0.6 Nm
    - nominal speed 3 rad/s
    - variable stiffness range [0.2 – 2] Nm/rad
    - rotation range* +/-90°
    - 100% Arduino compatible

qbmove

- A Natural Motion™ actuator
  you can download and build yourself
- Three versions:
  - Maker
  - Maker-pro
    - custom electronics and high-strength aluminum parts
    - nominal torque of 1.3 Nm
    - nominal speed 7 rad/s
    - variable stiffness range [0.6 – 8] Nm/rad
    - rotation range +/-180°
    - USB & RS485 communication (allows daisy-chain)

qbmove

- A Natural Motion™ actuator
  you can download and build yourself
- Three versions:
  - Maker
  - Maker-pro
  - Advanced
    - high-end, completely re-engineered from the bottom-up
    - nominal torque of 6.0 Nm
    - nominal speed 10 rad/s
    - variable stiffness range [0.6 – 30] Nm/rad
    - rotation range +/-180°
    - USB & RS485 communication (allows daisy-chain)

qbmove maker-pro - datasheet

qb robotics

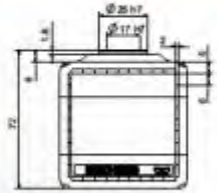
Fast *Flexible* Technology

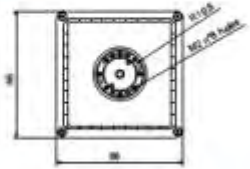
qb move MAKER PRO

DATA SHEET

Online Community www.naturalmotioninitiative.org

AGONISTIC / ANTAGONISTIC SERVO-VSA

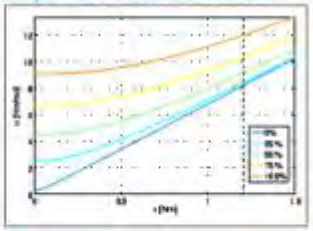




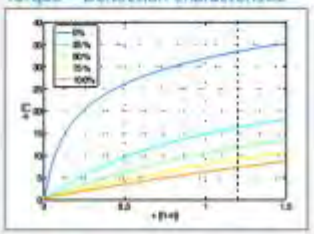
Main Specifications

#	operating data (quantity)	(unit)	(value)
	mechanical		
1	Continuous Output Power	[W]	4.8
2	Nominal Torque	[Nm]	1.2
3	Nominal Speed	[rad/s]	4
4	Peak (Maximum) Torque	[Nm]	1.5
5	Maximum Speed	[rad/s]	9.5
6	Maximum Stiffness	[Nm/rad]	1.3
7	Minimum Stiffness	[Nm/rad]	0.5
8	Nominal Vibration Isolation Time	[s]	0.2
9		[s]	0.2
10	Maximum Elastic Energy	[J]	0.19
11	Maximum Hysteresis	[°]	6
12	Maximum Deflection	[°]	9
13		[°]	16
14	Active Rotation Angle	[°]	180
15	Angular Resolution	[°]	360/32768
16	Weight	[kg]	0.460
	electrical		
17	Nominal Voltage	[V]	8
18	Nominal Current	[A]	2
19	Maximum Current	[A]	5
	control		
20	Voltage Supply (USB)	[V]	3.3 - 5
21	Nominal Current (USB)	[A]	0.26
22	I/O protocol	[]	RS485 | USB

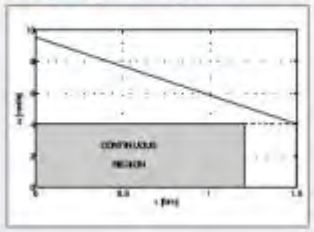
Torque – Stiffness characteristic



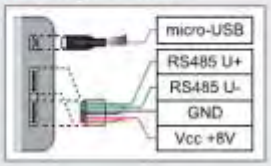
Torque – Deflection characteristic



Torque – Speed characteristic

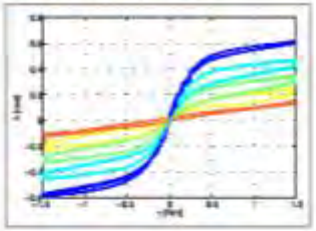


Electrical connections

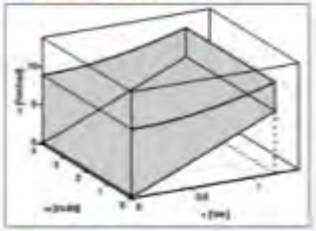


qbmove maker-pro - datasheet

Experimental Torque
Deflection characteristic



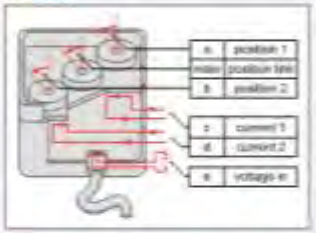
Torque – Speed
Stiffness Workspace



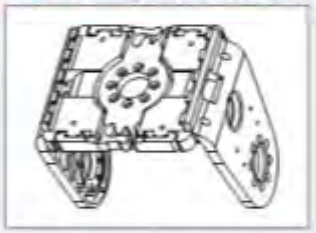
Additional sensors data

	operating data		
#	quantity	unit	value
a0	mechanics		
a1	Resolution	[]	65536
a2	Range	[]	360
a3	I/O protocol	[]	mLVDS
b0	Sensor b – motor 2 position		
b1	resolution	[]	65536
b2	Range	[]	360
b3	I/O protocol	[]	mLVDS
c0	Sensor c – motor 1 current		
c1	Resolution	[A]	3/1638
c2	Range	[A]	0,39
c3	I/O protocol	[]	6
d0	Sensor d – motor 2 current		
d1	Resolution	[A]	38
d2	Range	[A]	0-1
d3	I/O protocol	[]	analogout
e0	Sensor e – input voltage		
e1	Resolution	[V]	255/4,98
e2	Range	[V]	0-15
e3	I/O protocol	[]	analogout

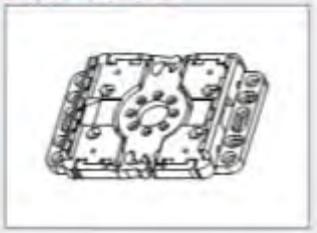
Sensors



Snap-on C-flange (not included)



Snap-on base-flange

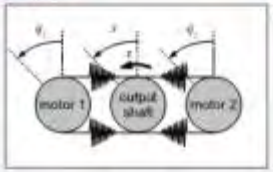


Snap-on flat-flange (not included)

qb robotics — Fast *Flexible* Technology

SKETCH — qbmove MAKER PRO

Layout



Nonlinear spring

Model parameters

	value	unit
k_1	0.0227	Nm
a_1	6.7328	1/rad
k_2	0.0216	Nm
a_2	6.9602	1/rad

Mathematical model (approx.)

101	equilibrium point	$q_e = (q_1 + q_2)/2$
102	output stiffness	$\sigma = a_1 k_1 \cosh(a_1 (x-q_1)) + a_2 k_2 \cosh(a_2 (x-q_2))$
103	output torque	$\tau = k_1 \sinh(a_1 (x-q_1)) + k_2 \sinh(a_2 (x-q_2))$
104	elastic energy	$H = \frac{k_1 (\cosh(a_1 (x-q_1))-1)}{a_1} + \frac{k_2 (\cosh(a_2 (x-q_2))-1)}{a_2}$

Open distribution model

project component	open license
mechanical drawings	CC BY (Creative Commons Attribution)
electronic schematics	CC BY (Creative Commons Attribution)
micro-controller firmware	3-clause BSD license
software libraries	3-clause BSD license

Online Community
naturalmotioninitiative.org

our website
qbrobotics.com

page 2 / sketch

qbmove: a simple interface

- A qbmove is easy to control as a servomotor
- Two digital signals command
  - Equilibrium Position
  - Stiffness
- On-board sensors read, control and transmit internal configuration data and position of the output shaft

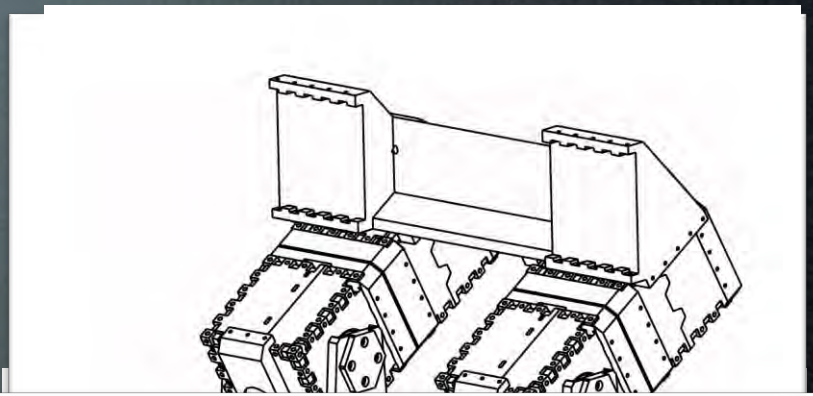
qbmove: a simple interface

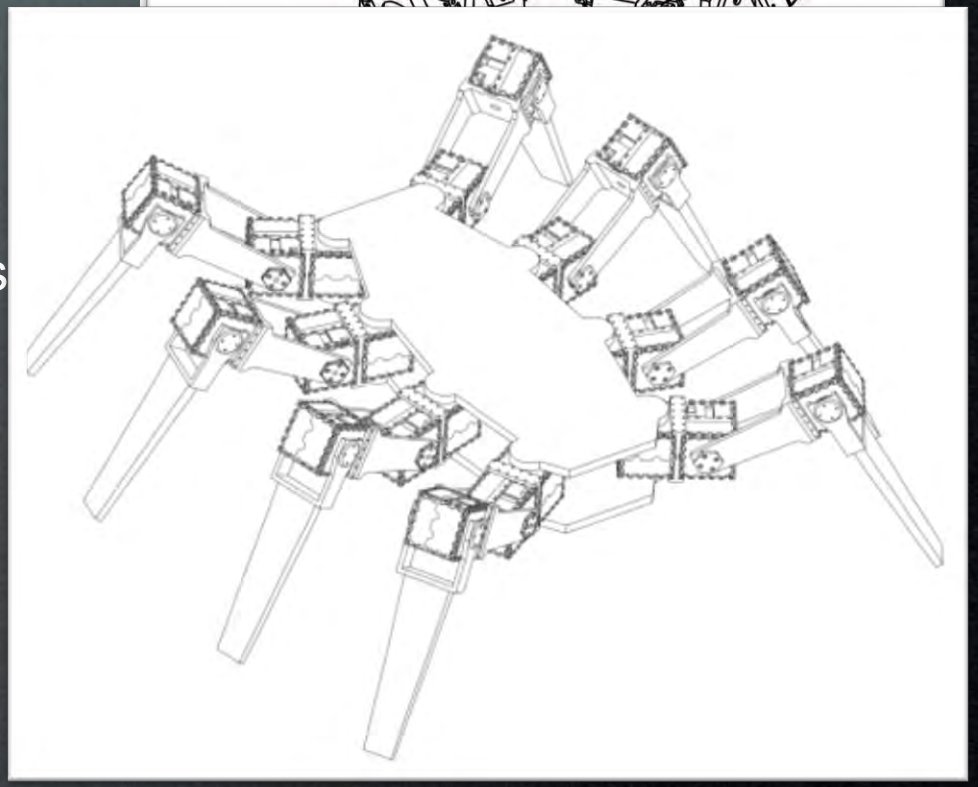
- Controlling a *qbmove* in Simulink: just *drag & drop* a block
- Controlling a *qbmove* in C: just *#include* a library
- Seamless ROS integration

```
1  //===============    includes
2
3  #include "qbmoveAPI/qbmove_commun
4
5  //===============    your code
6
7  int main() {
8      //Open port
9      openRS485(&comm_settings, por
10
11     //Retrieve measurements
12     commGetMeasurements(&comm_set
13
14     //Retrieve currents
15     commGetCurrents(&comm_setting
16
17     //Set new position
18     commSetInputs(&comm_settings,
19
20     return 1;
21 }
```

qbmate

- A ready-to-play robotic development kit, made of several *qbmove* units, and interconnection elements
  - Starter kit: 6 maker-pro units
  - Full kit: 12 units
    (10 maker-pro, 2 advanced)
  - Advanced kit: 12 units
    (6 maker-pro, 6 advanced)





qbmove & *qbmate*

qbmove maker and maker-pro are now up for grabs (or off the shelf)

- *qbmove* advanced will be ready early this year
- all design (hardware, electronics, software, etc..) are **open** and **free** to download and replicate:

www.naturalmotioninitiative.com

- qbrobotics can provide ready-made *qbmove* units and *qbmate* kits

www.qbrobotics.com

qbmove

Three versions:

- Maker
- Maker-pro
- Advanced

Version	€	Availability
Maker	400	now
Maker-pro	600	now
Advanced	1000	2014

qbmate

Three versions:

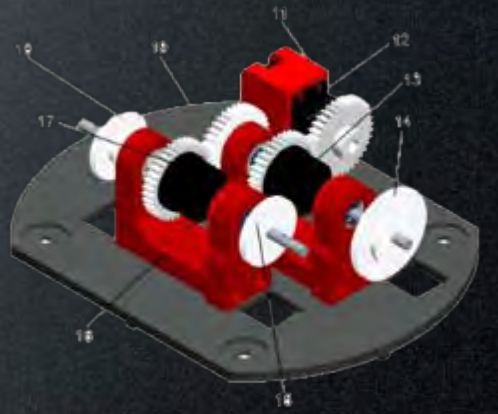
- Maker
- Maker-pro
- Advanced

Version	€	Availability
qbmate starter kit	4000	now
qbmate kit	8000	early 2014
qbmate plus kit	12000	early 2014

RRP Hand (THE first)

THE Second Hand

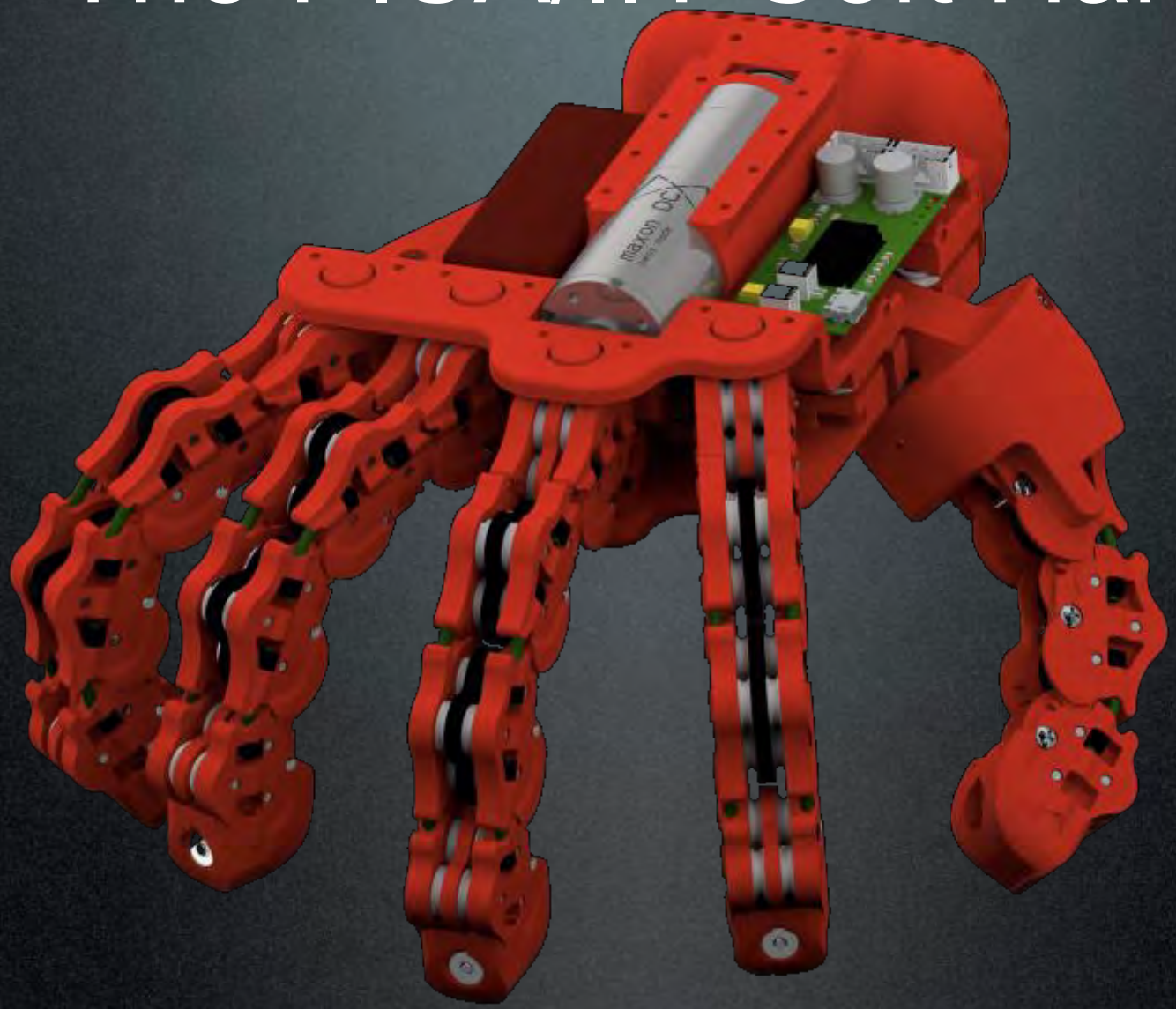
a MECCANO of Synergies!



- Modular design
- Differential gear stages
- Compositional Design
- Toward Minimalism

G. Grioli, M. Catalano, E. Silvestro, S. Tono and A. Bicchi, "Adaptive Synergies: an approach to the design of under-actuated robotic hands," in *Intelligent Robots and Systems, 2012. IROS 2012.* [subm].

The PISA/IIT Soft Hand



Thank you