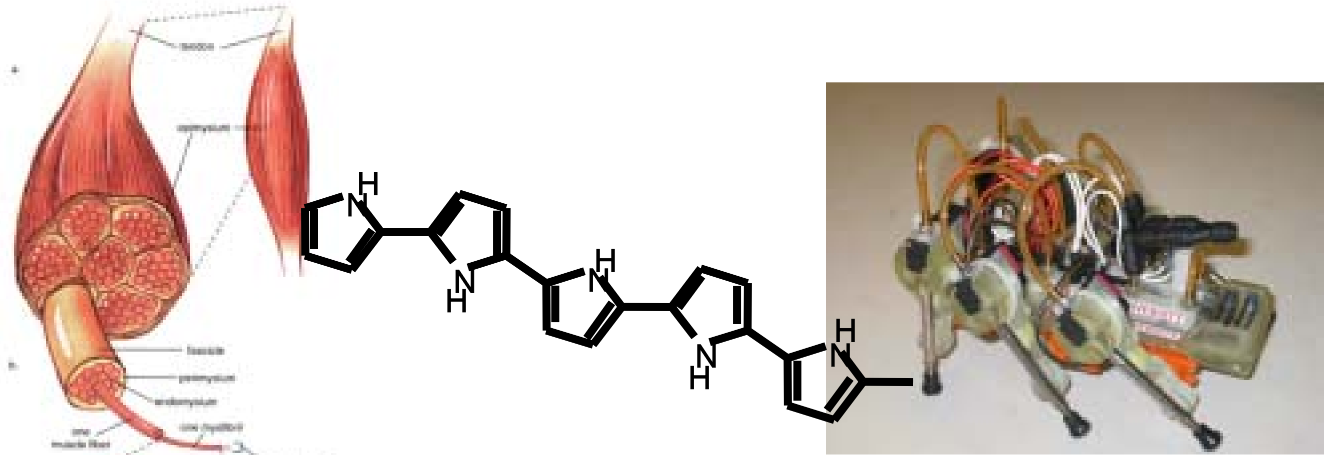
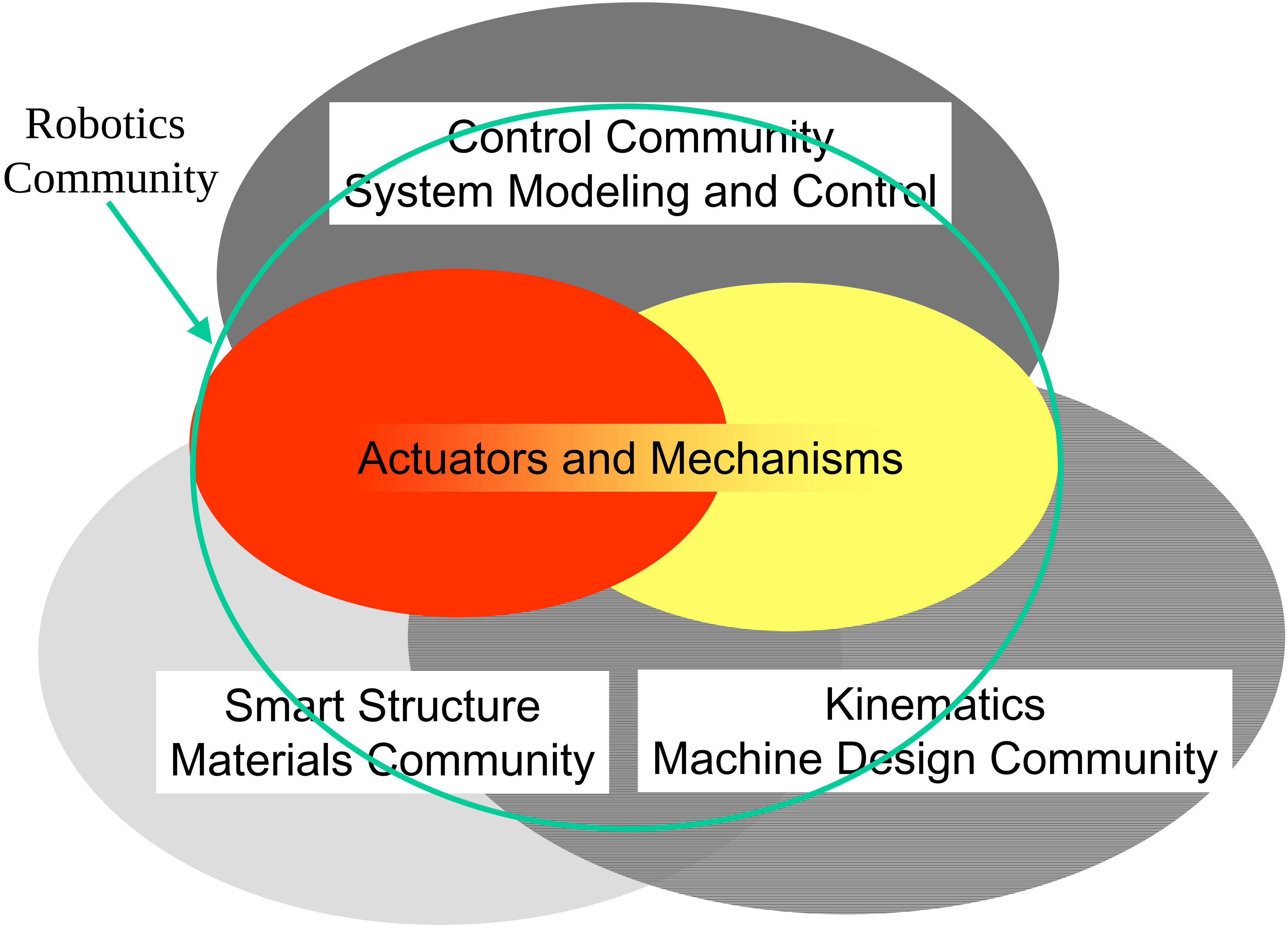
WTEC Workshop on the Status of Robotics in US



Actuators and Mechanisms

H. Harry Asada

MIT


Robotics Community
Control Community
System Modeling and Control
Actuators and Mechanisms
Smart Structure
Materials Community
Kinematics
Machine Design Community

Major laboratories and investigators

- Stanford

  M. Cutkosky, Center for Design Research

  K. Waldron, B. Roth; Mechanical Engineering

- UC Berkeley

  Hami Kazerooni, Human Engineering and Robotics Lab

- Carnegie-Mellon

  Khosla, Hollis, Choset; Robotics Institute

- MIT

  Tim Swager, Soldier Nanotech Lab; Hunter Bioinstrumentation lab, Dubowsky, Space & Field Robotics Lab; Asada, d'Arbeloff Lab

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- Sarcos/Utah

  Steve Jacobson

Most influential (High Profile) projects conducted in the last 10 years

- Kazerooni’s robotic exoskeleton
- Cutkosky’s Sprawlite: Shape deposition mfg
- Swager/Hunter/Madden’s conducting polymer actuators

- Jacobson’s entertainment robots
- Massie’s PHANToM
- Karmen’s Segway human transport

Hami Kazerooni's Robotic Exoskeleton
UC Berkeley, Human Engineering and Robotics Lab

70 lb backpack

IC engine

Hydraulic Actuators

Local Area Network

100 lb

Instrumented Shoes

Feeling lugging a mere 5 pounds

Mark Cutkosky
Biomimetic Design and Fabrication of a Hexapedal Running Robot
Stanford University, Center for Design Research

Rear feet for kicking

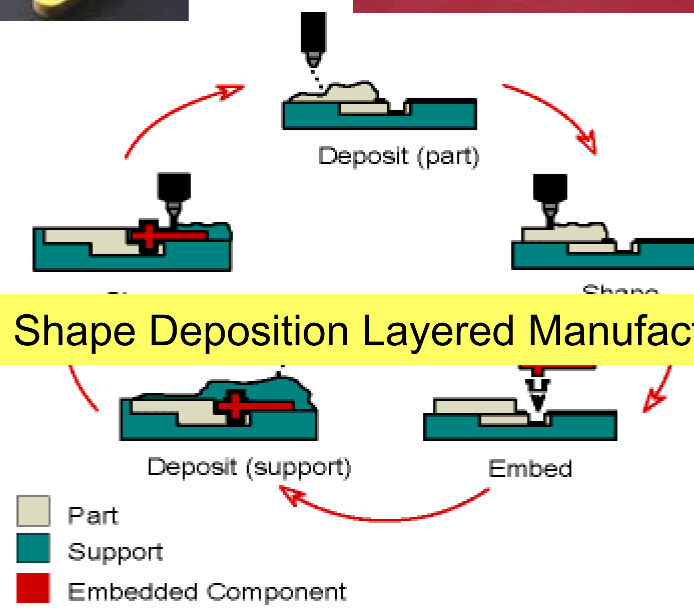
Front feet for control

Built-in compliance

5 body-lengths per second

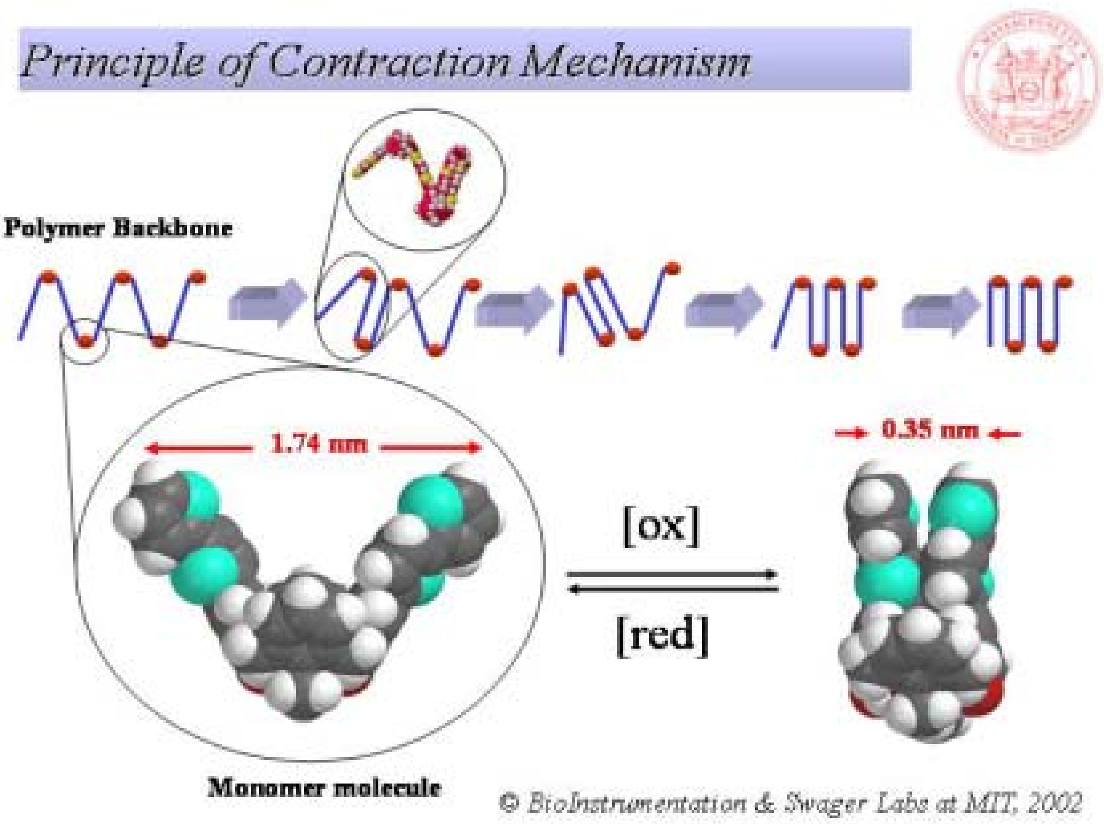
Actuators, wires, and sensors embedded inside structure

Shape Deposition Layered Manufacturing



J. Clark, J. Cham, S. Bailey, E. Froehlich, P. Nahata, R. Full (UC Berkeley, Biology), M. Cutkosky, Proc. 2001 IEEE ICRA

MIT
Tom Swager, Solder Nanotech Lab & Chemistry
Ian Hunter, Bioinstrumentation Lab, Mechanical Engineering



Initial results on a new conducting polymer actuator show strains of 6% against an applied load of 1 MPa at a strain rate of 1% per second.
The material is Poly EDOT and it is actuated electrochemically in the ionic liquid BMIMBF4.
The results will be presented in two weeks at the SPIE 11th Annual International Symposium on Smart Structures and Materials.

Most influential (but publicly less known) papers published in this area (Last 10 years)

- Goldfarb's monopropellant powered actuators

  M.Gogola, E.J.Barth, M. Goldfarb, "Monopropellant powered actuators for use in autonomous human-scale robotics", Proc. 2002 ICRA

- Khosla's modular robots ← Fukuda's modular robots, 1989

  C.J.-J. Paredis and P.K. Khosla, "Kinematic Design of Serial Link Manipulators from Task Specifications", Int. J. Robotics Research, 12-3, 1993

- Chirikjian's binary actuation paradigm

  G.S. Chirikjian, "A binary paradigm for robotic manipulators", Proc. IEEE ICRA 1994.

  → Binary modular reconfigurable robots by Dubowsky

- B. Donald's actuator arrays

  K.F. Bohringer, B. Donald, R Mihailovich, N. MacDolald, "A theory of manipulation and control for microfabricated actuator arrays, Proc. IEEE ICRA, 1994

  → Distributed manipulation systems by Luntz, Messner, Choset, 1999; Murphey and Burdick 2004

- Solid-State (peltier-effect) SMA by A.R. Shahin, P. Meckl, J. Jones, M. Thrasher

  "Enhanced cooling of shape memory alloy wires using semiconductor heat pump modules, J. of Intelligent Material Systems and Structures, 5-1, 1994.

- Hollis' magnetically levitated hand

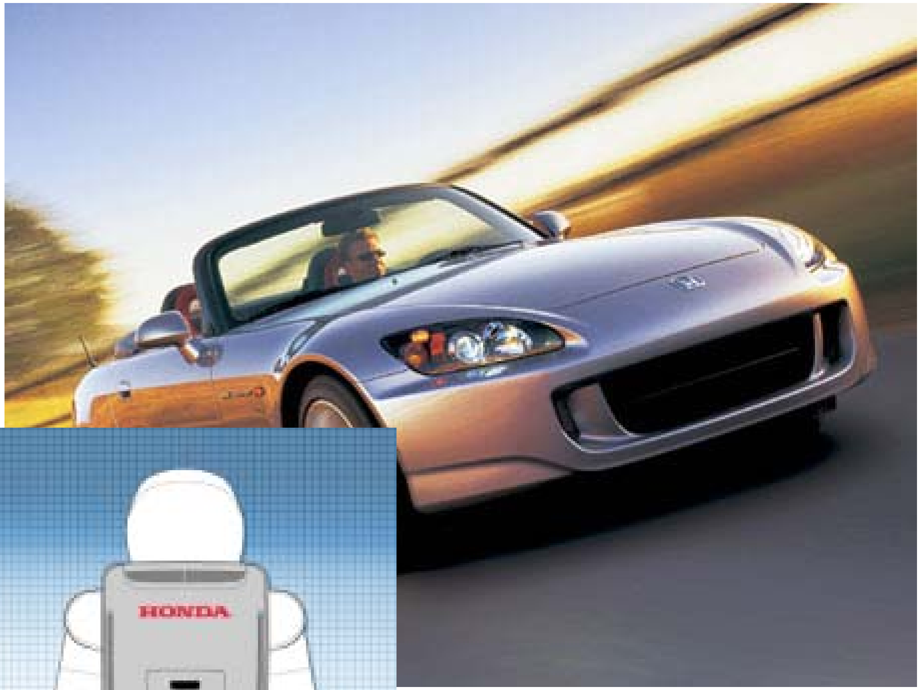
Most influential papers published in this area (Historical Importance)

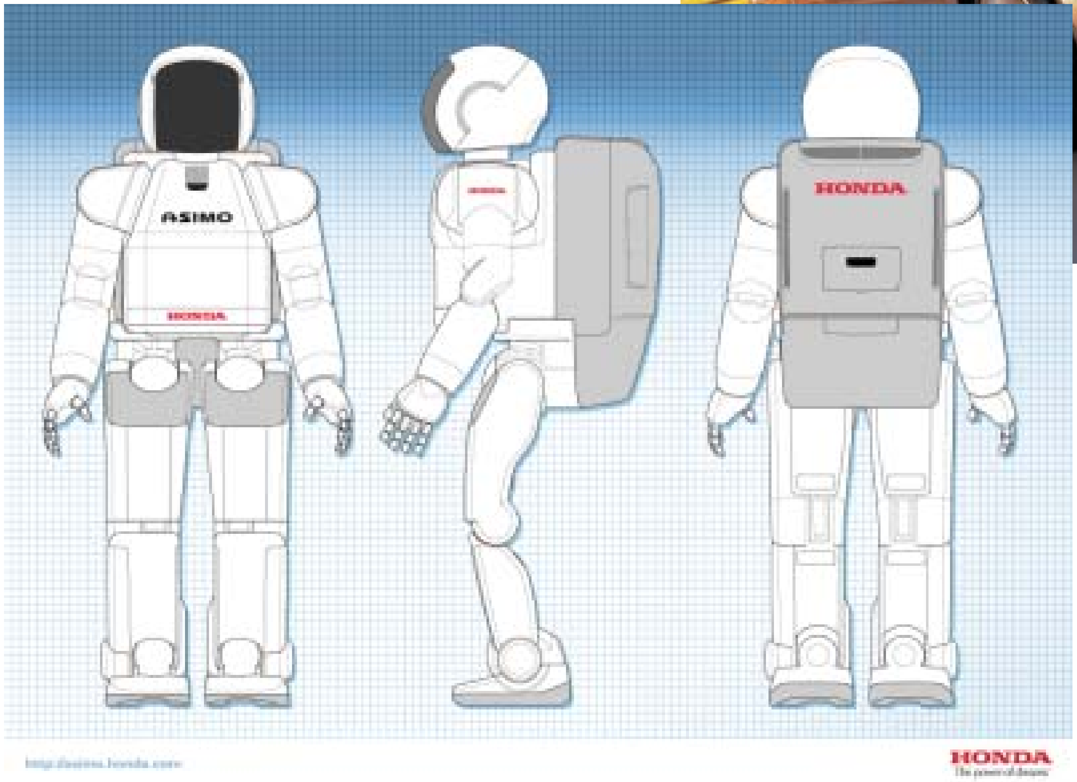
- Roth’s work space kinematics
- Whitney’s RCC (Remote center Compliance) Hand
- Asada’s direct-drive robots
- Raibert’s hopping robots
- Salisbury’s multi-fingered hands
- Waldron’s hexapod robot

Major accomplishments in other countries

- Kato’s biped robots
- Hirose’s snake robots
- Makino’s SCALA robot
- NSK’s direct drive motors
- Harmonic drives
- Ultrasonic motors by S.Ueha, Y. Tomikawa, M. Kurosawa, N. Nakamura, 1993
- Soft gel actuators: Y. Osada, 1992; S. Tadokoro, 2000; H. Inoue, 2002.
- Fukuda’s modular robots, 1988
- Honda’s Asimo
- Sony’s Aibo

Honda Shock





SONY Shock

It’s a SONY

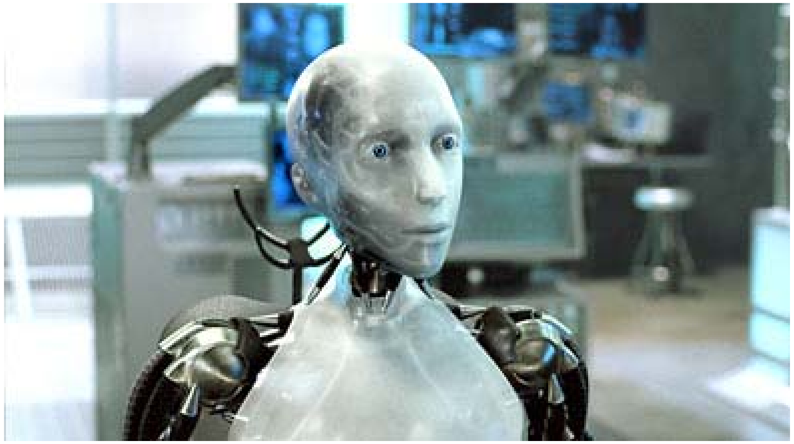
ISA – Actuator

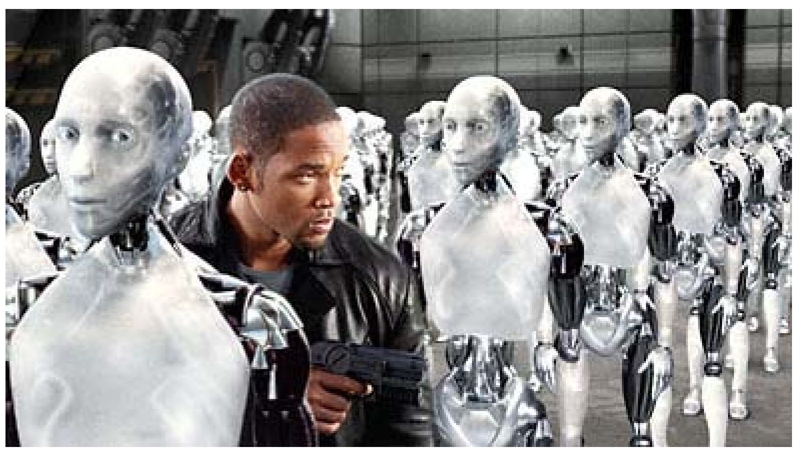
In order for QRIO to walk and dance so skillfully, an actuator was needed with the ability to produce varying levels of torque at varying rpm speeds, respond with quickness and agility, not be affected by outside forces -- and do all of this efficiently. We found a way to make a smaller actuator with broadly improved function and precision. In addition, QRIO's gears are precise, quiet, and highly dependable

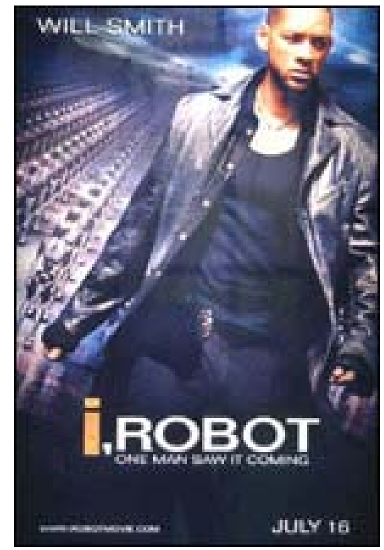
Segway

Now, somewhat obsolete

And we have only movies in US…….



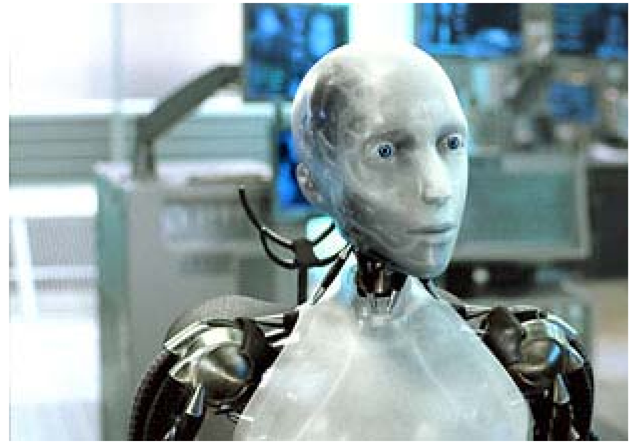




Major unsolved problems and challenges to be overcome for progress in this area

- Electroactive polymer actuators that do not break
- SMA: faster, more accurate,….
- Integration with energy generation/co-generation
- Technology to build over 100 DOF actuators: Scalable
- Automatic impedance matching & field-programmable actuators/mechanisms

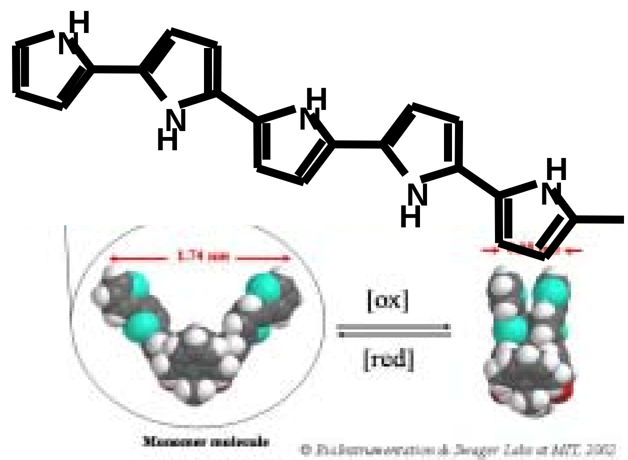
Robotics: Systems



Fill the technology gap

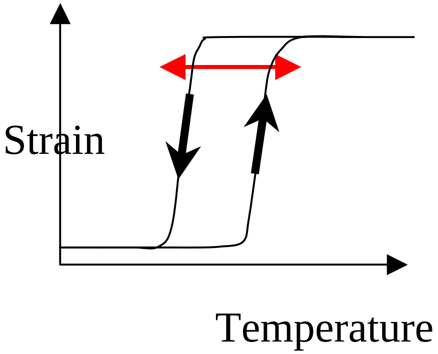
We cannot wait!

Materials Technology

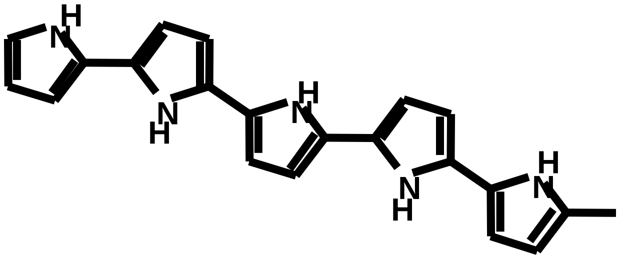


Material-Based Actuators:
Highly complex and nonlinear

Shape Memory Alloy

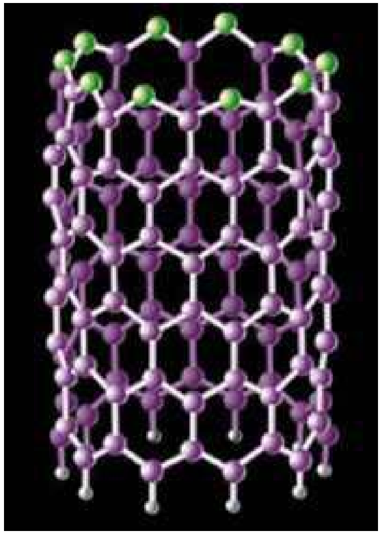


Conducting Polymer Actuators

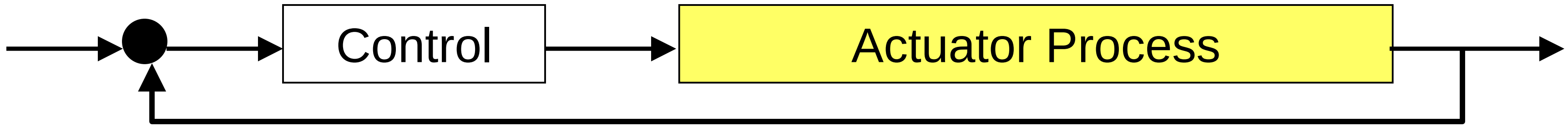


Ion intercalation severely limits the life and rate of conducting polymer actuators

Carbon Nanotube Actuator

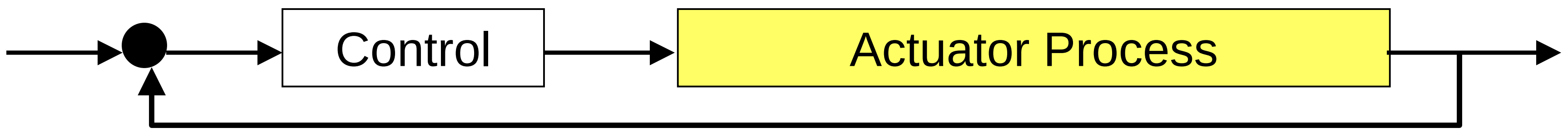


The Traditional Approach to these systems is “BULK” FEEDBACK.



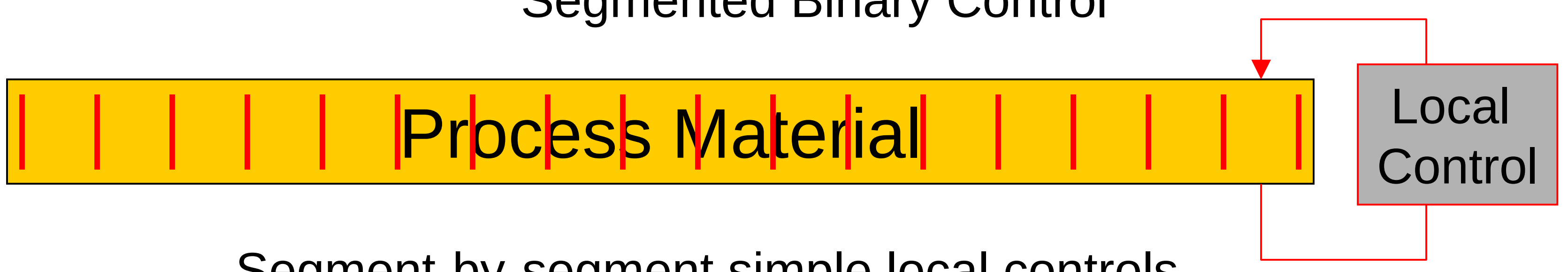
Since the process is highly distributed and nonlinear, bulk feedback does not work well.

The Traditional Approach to these systems is BULK FEEDBACK.



Since the process is highly distributed and nonlinear, bulk feedback does not work well.

New Approach:
Segmented Binary Control

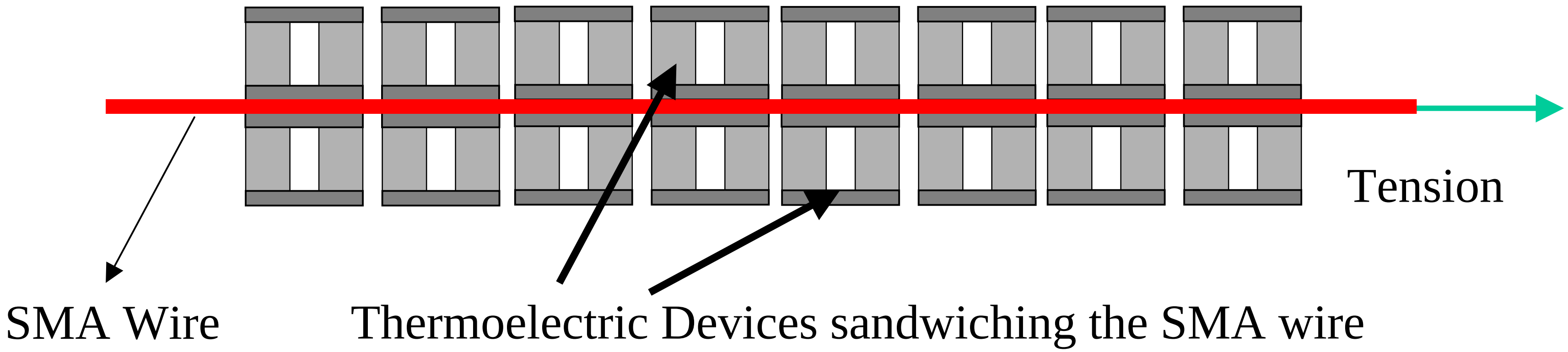


Segment-by-segment simple local controls
(binary, finite state controls)

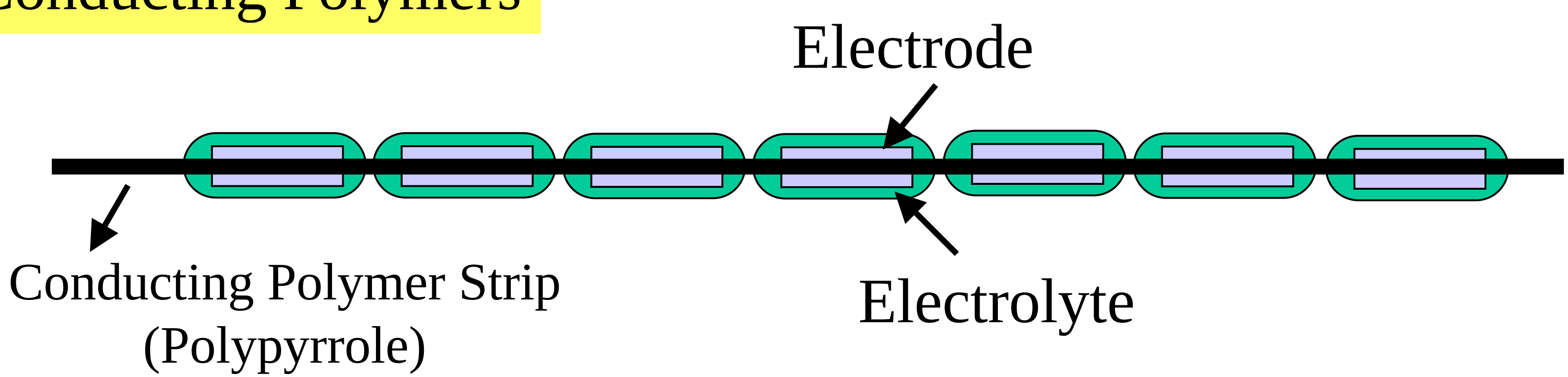
Implementation of Segmented Binary Control

SMA

Use of Thermoelectric devices (Peltier Effect) for heating and cooling of SMA wires

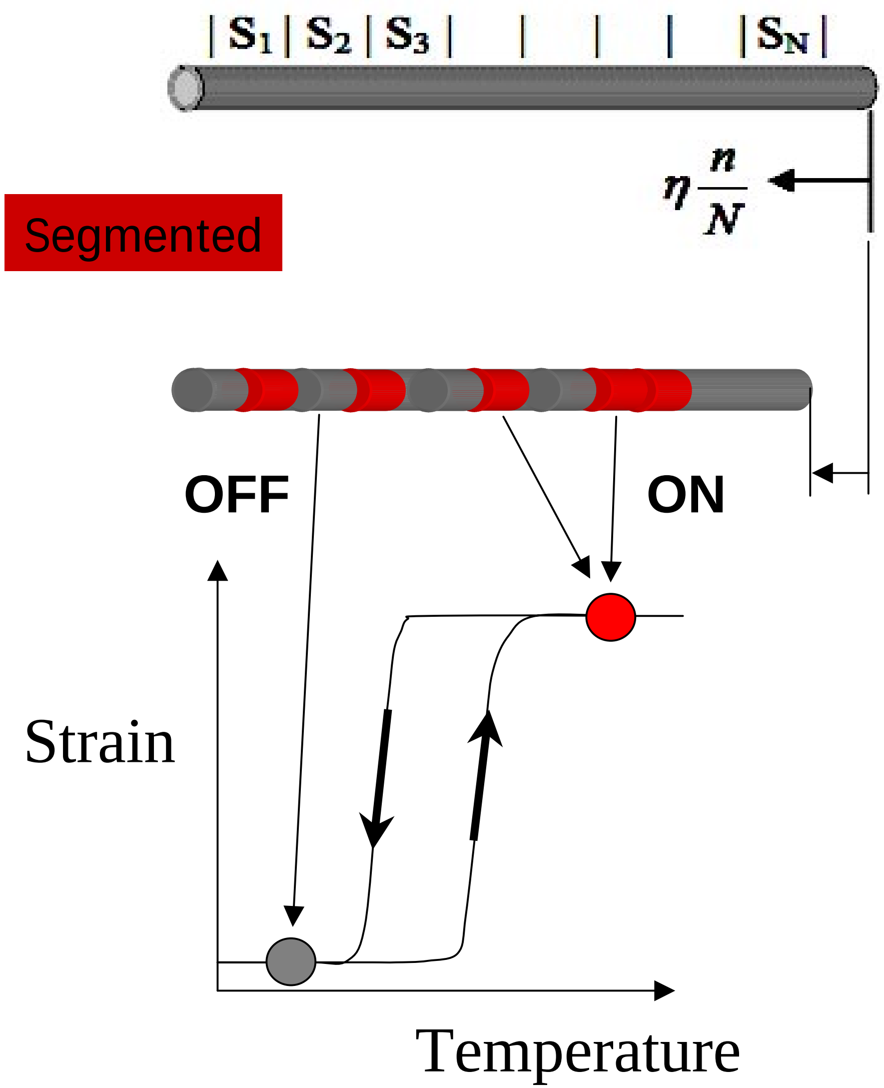


Conducting Polymers



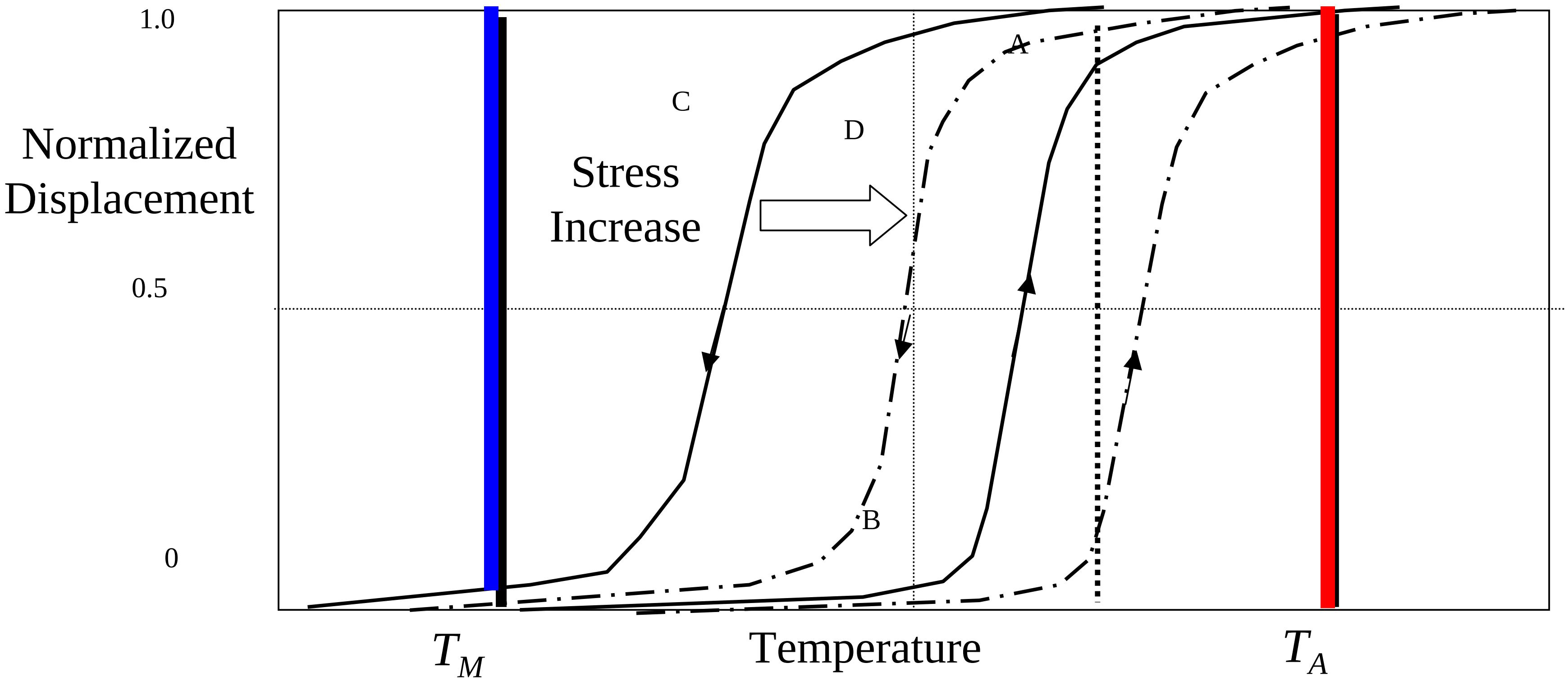
Segmented Binary Control

- Divide the whole into a multitude of smaller segments controlled separately.
- Overall strain is the sum of the individual strains for each segment



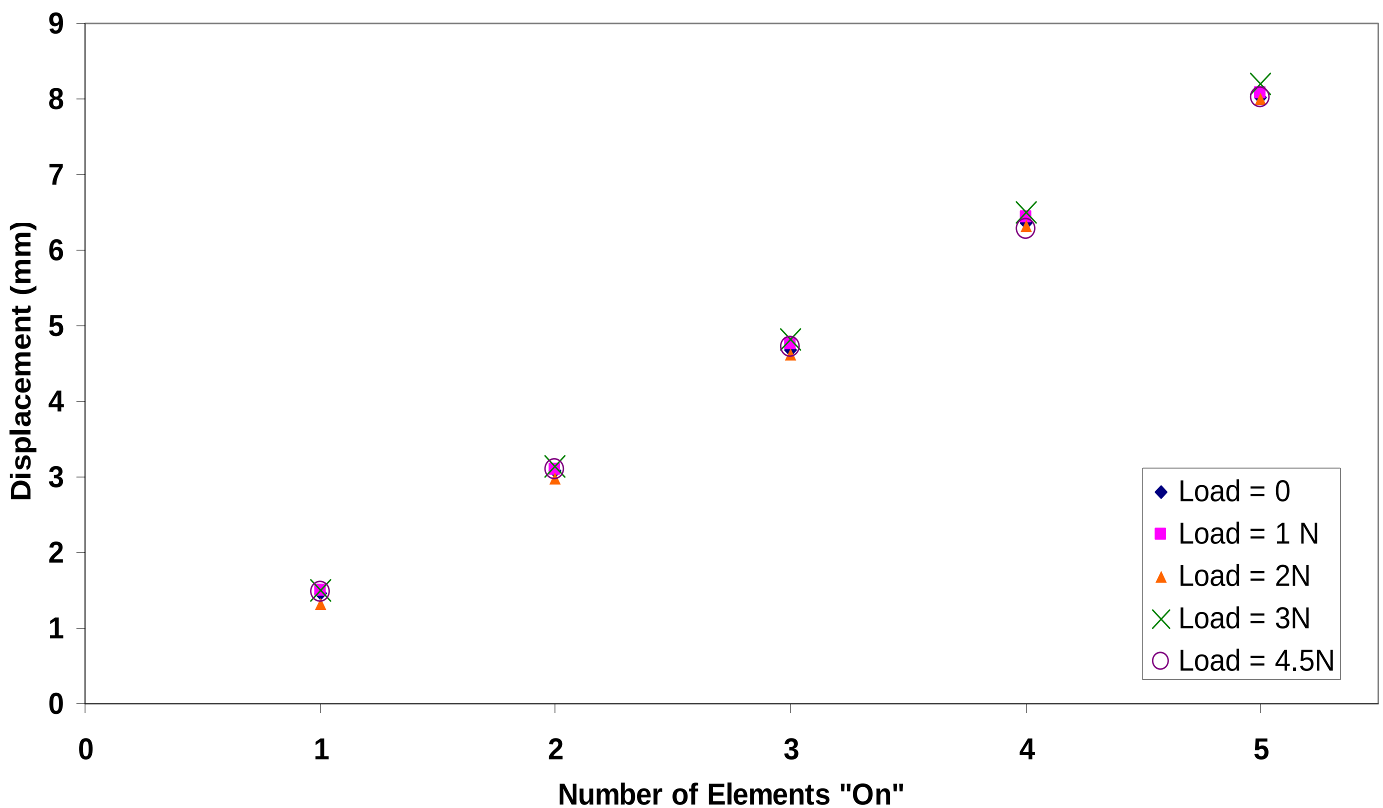
Binary State Controls

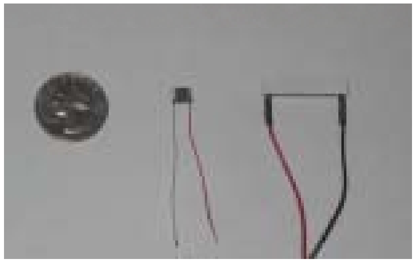
- Each segment may take either hot state or cold state
- Wash out all material hysteresis and nonlinearities

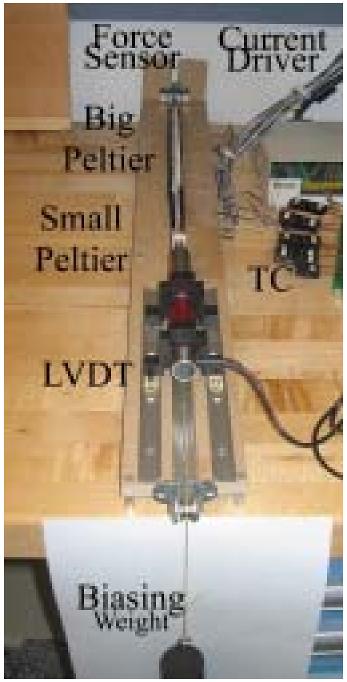


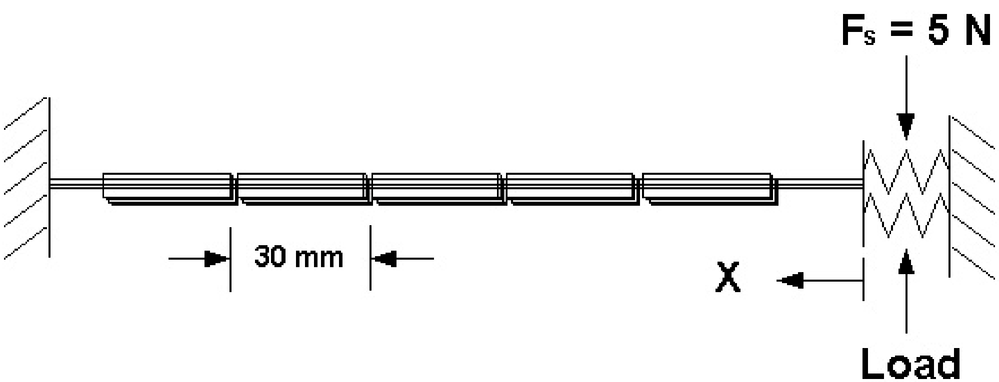
Phase transition diagram of SMA and selection of threshold temperature T_A and T_M

Segmented Binary Control:
SMA works like a stepping motor





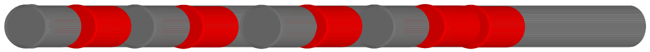


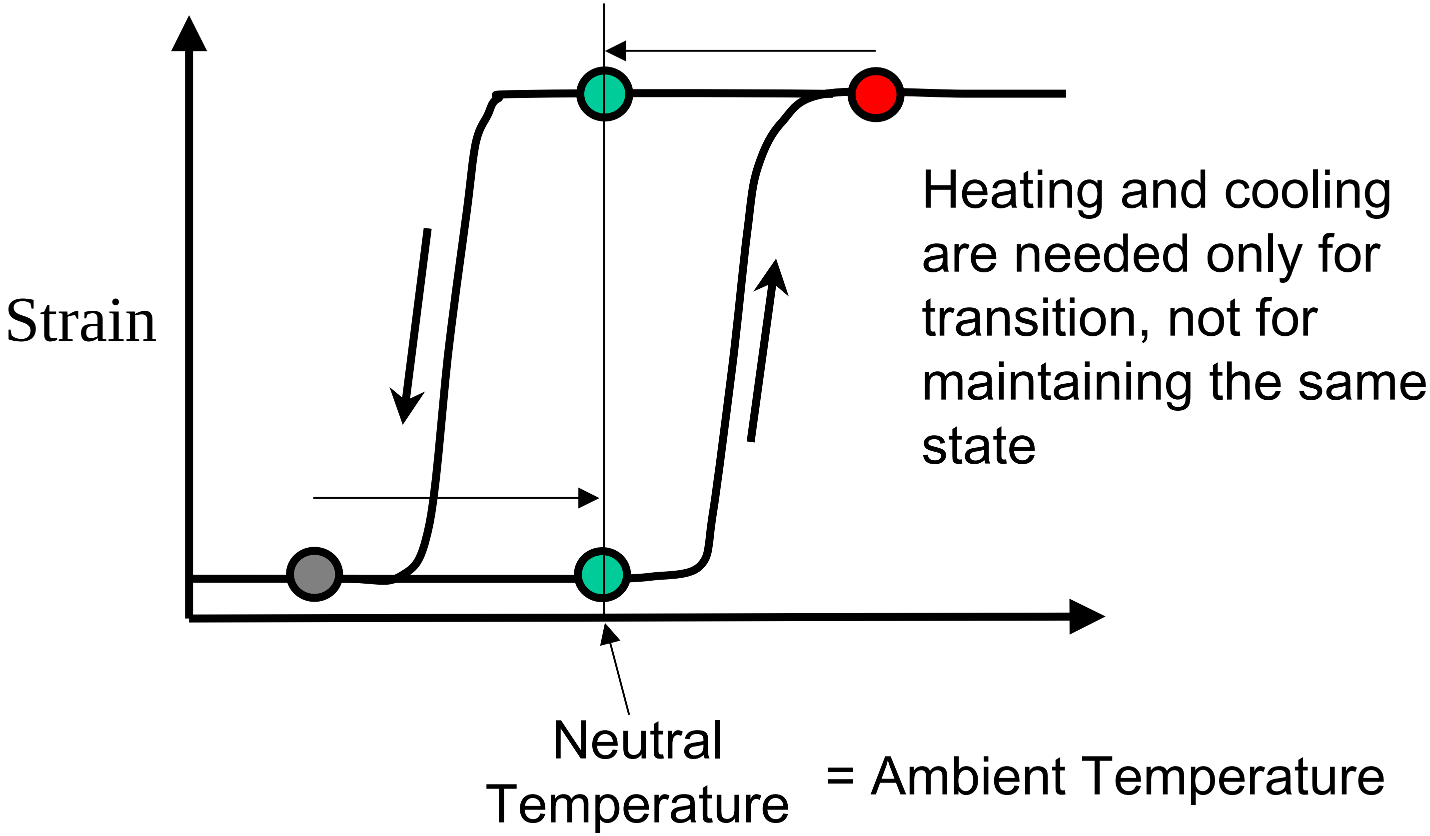


$$X = \eta \frac{n}{N}$$

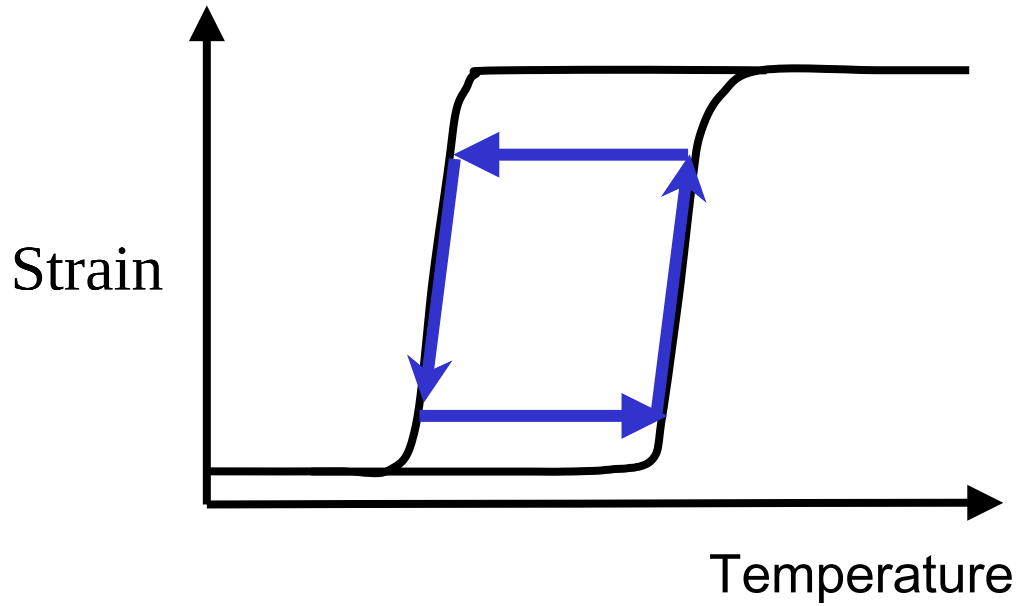
$$\eta \approx 1.6mm$$

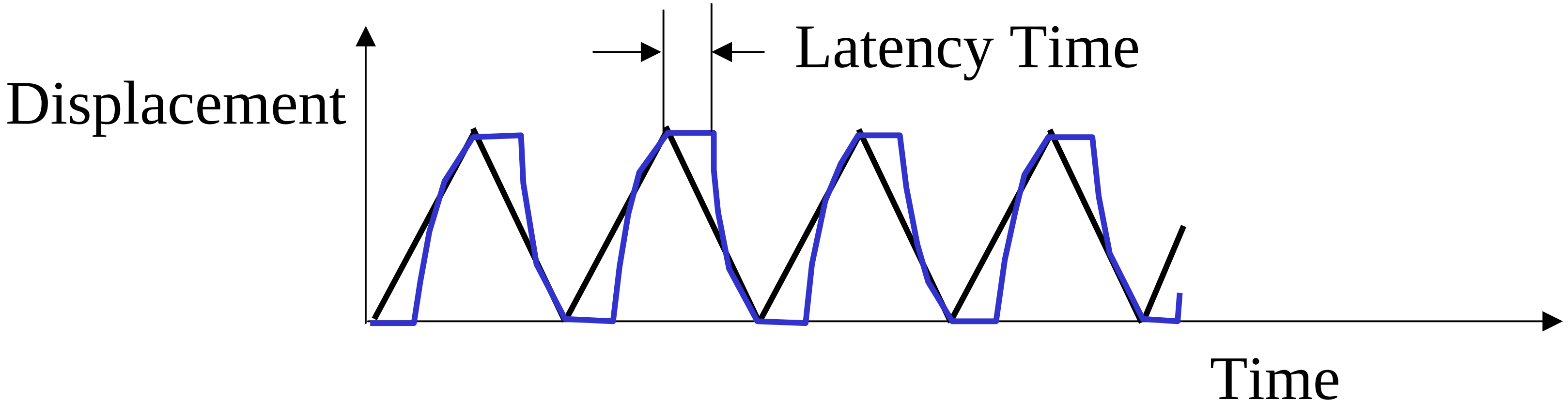
Exploiting "Hysteresis"





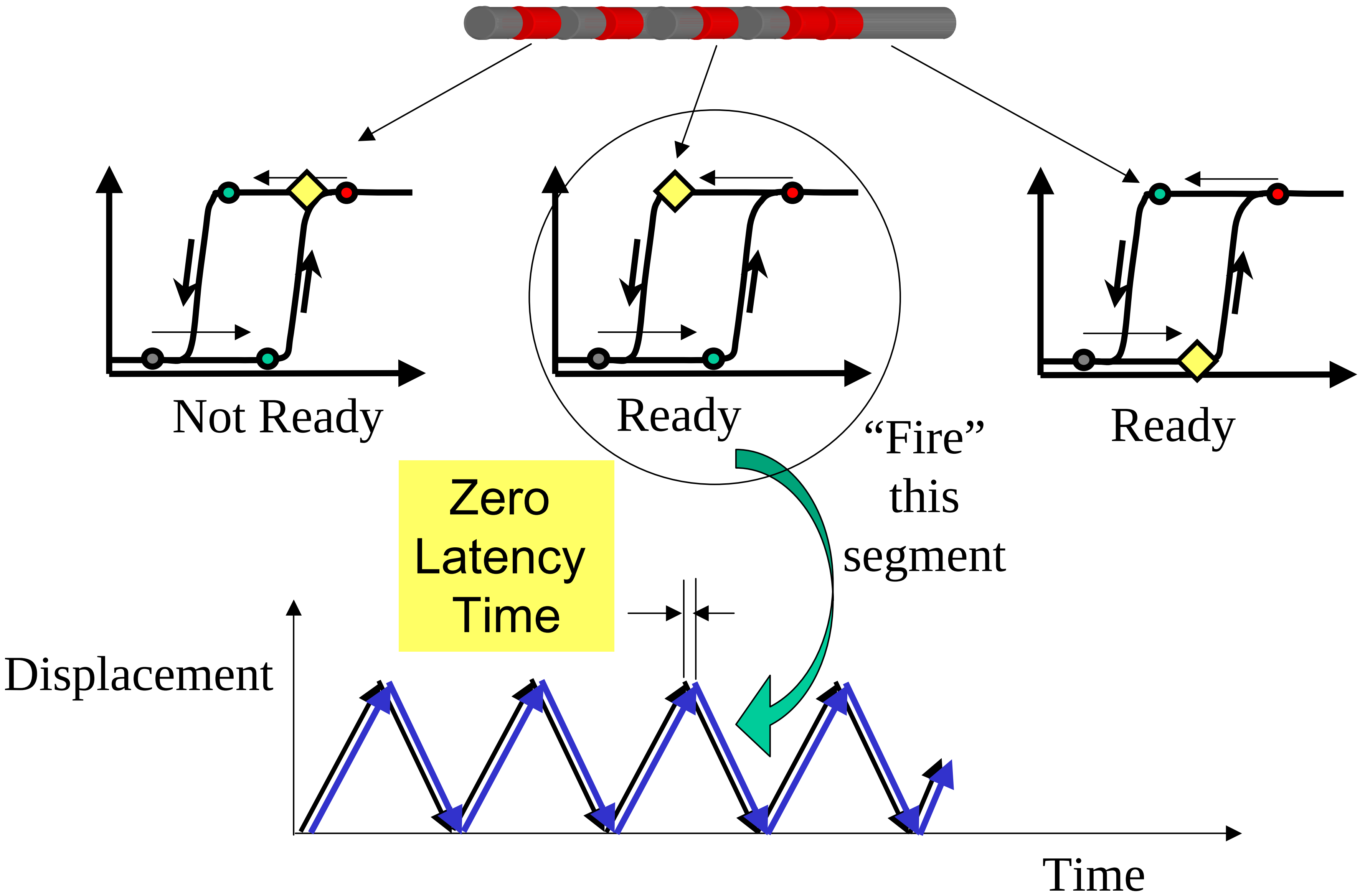
Drawback of traditional SMA control



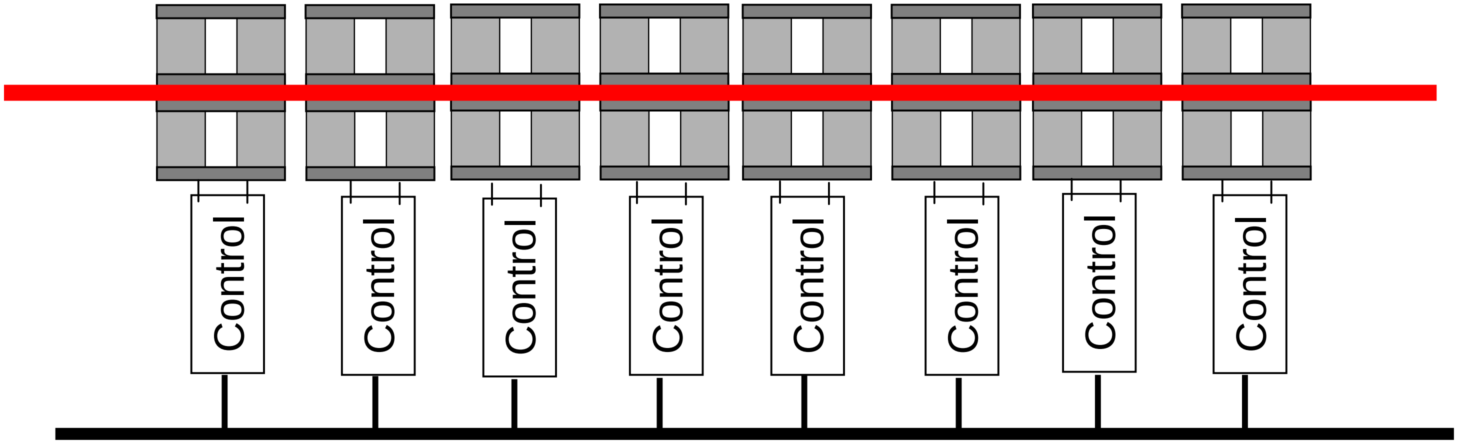


The traditional approach cannot avoid the latency time.

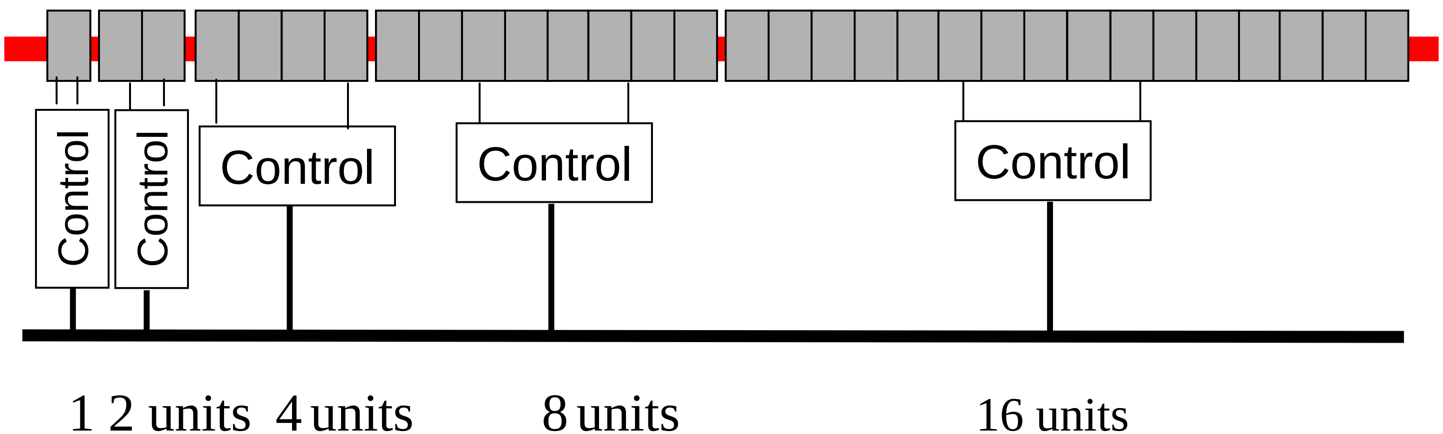
Multi-Segment Coordination



Drawback: Too many controls

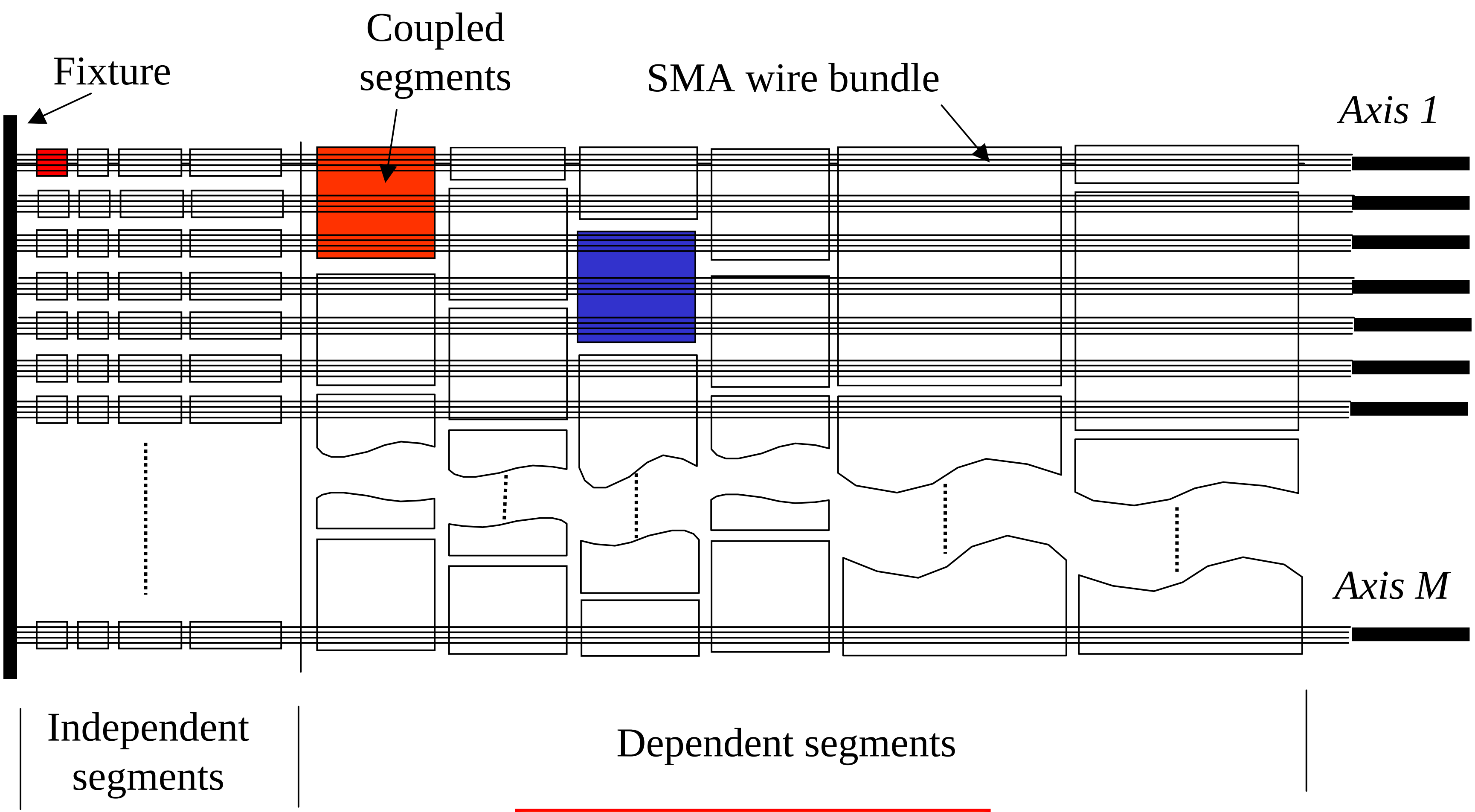


Solution: Grouping



Minimum segmentation of single axis

Two-dimensional segmentation of multi-axis SMA actuator system on Peltier pellet bed



Array Actuators

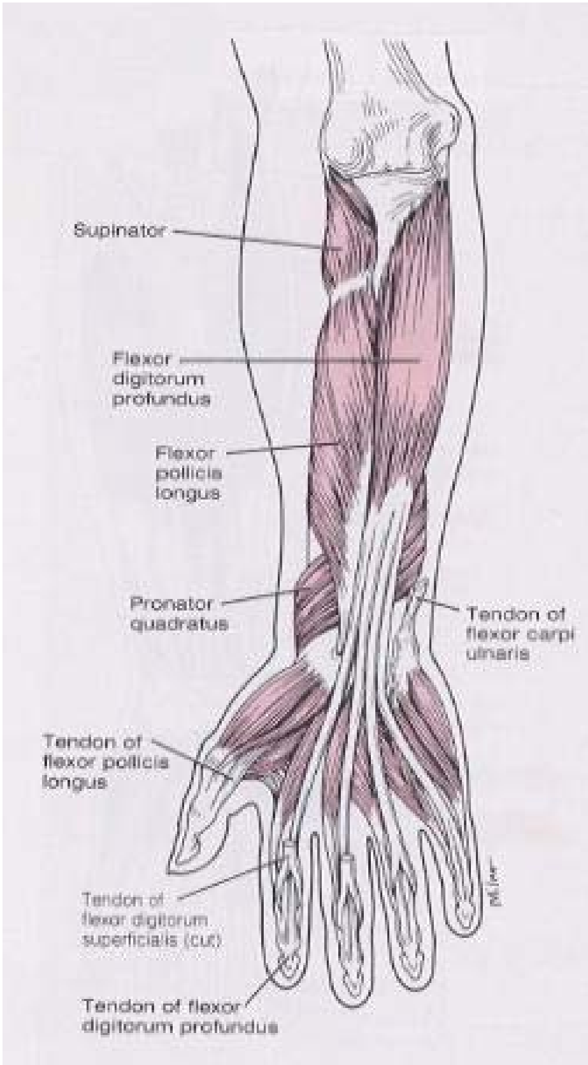
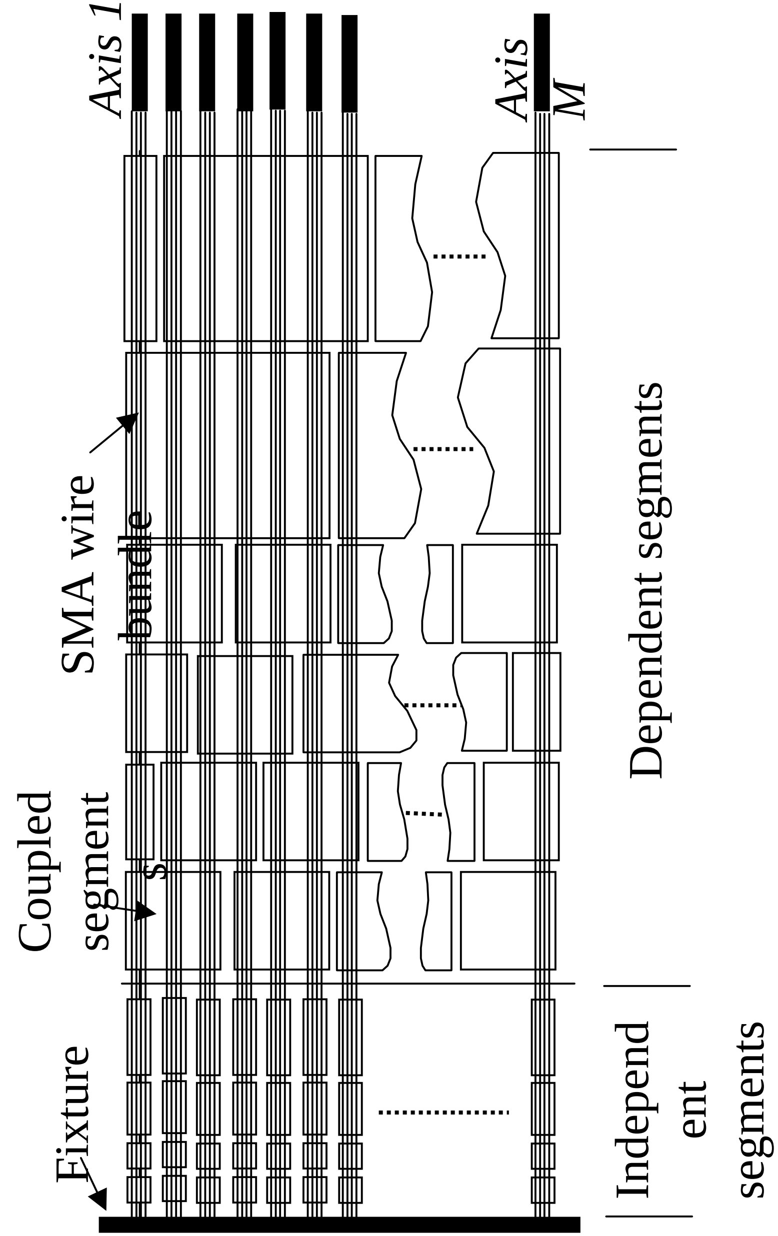
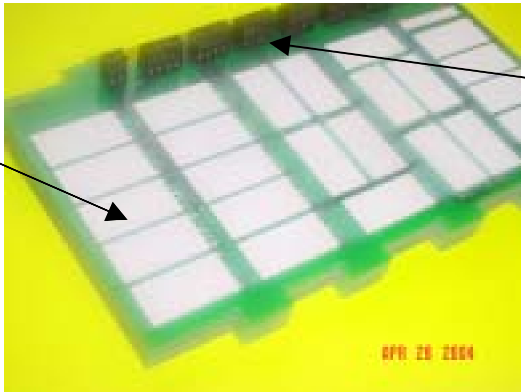


Figure 10 Deep anterior muscles of the right arm[1]



10 Axes of actuator array controlled by 12 ON-OFF controllers

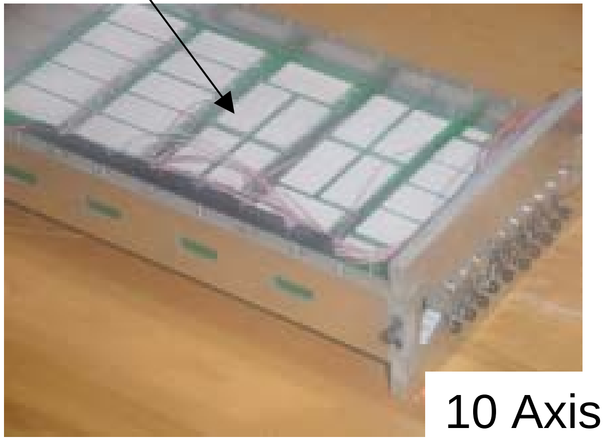
Peltier Effect
Thermoelectric Devices

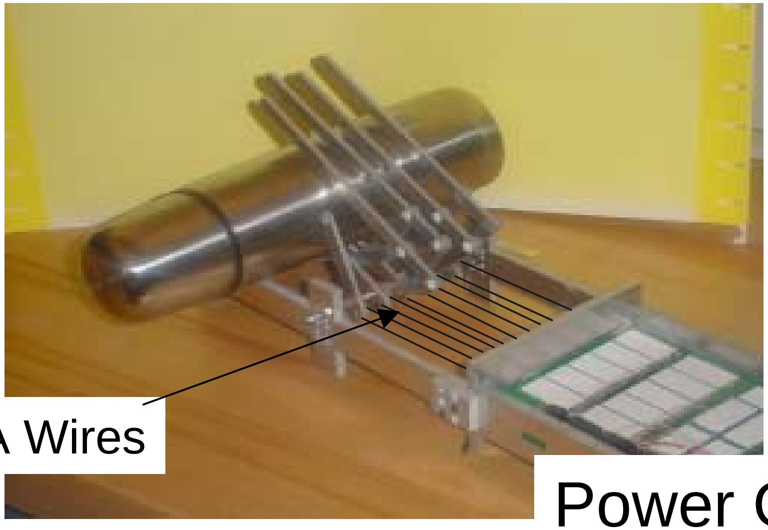


Programmable Array
Jumper Cable Terminals

Five-Fingered Hand
With 10 DOF Actuators

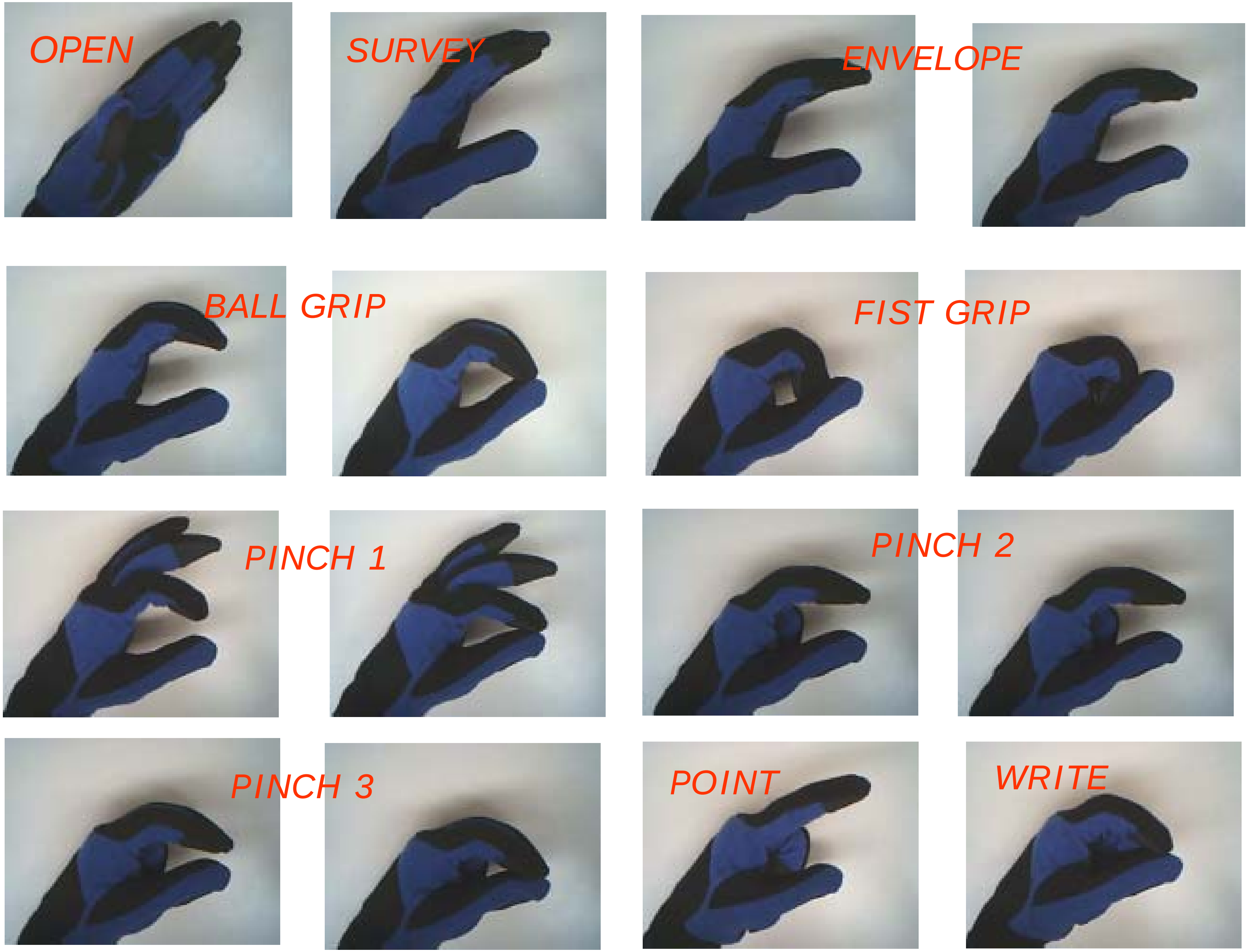
Temperature Sensors



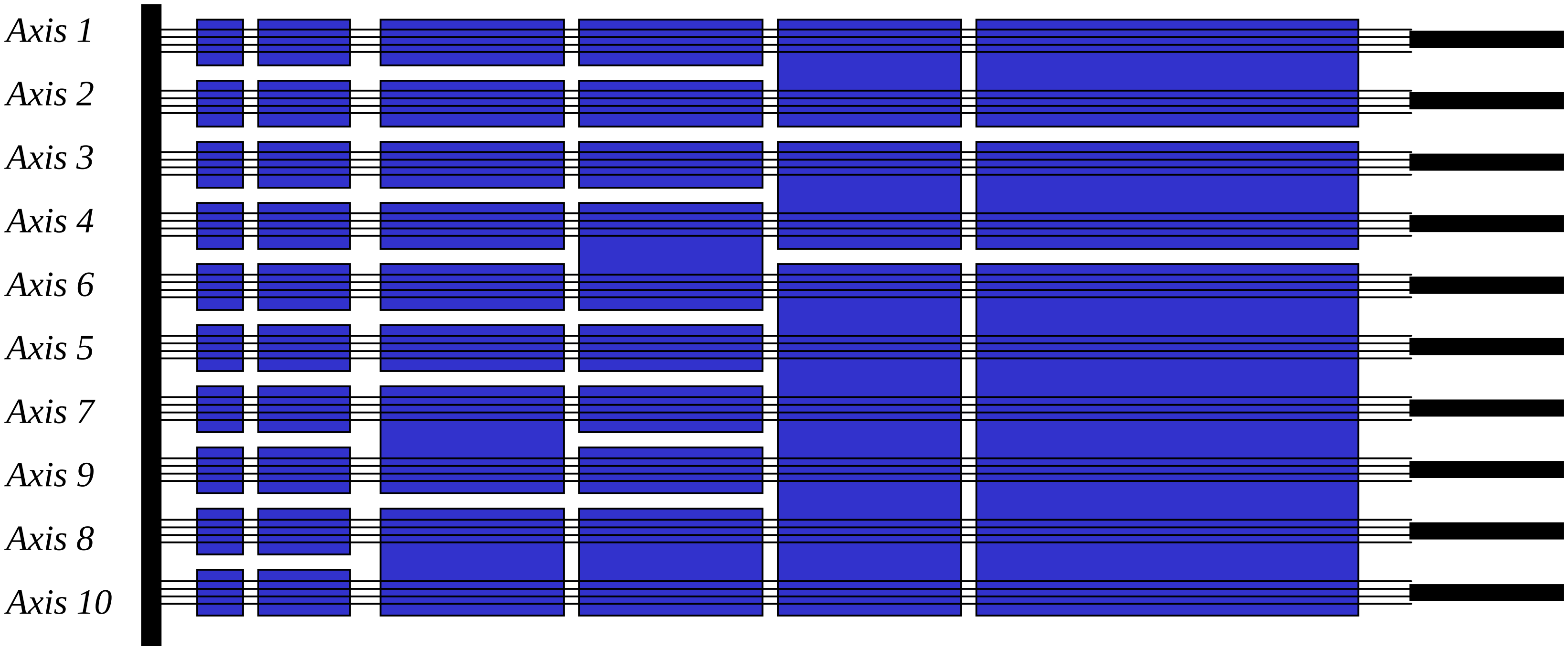


10 Axis SMA Wires

Power Grip

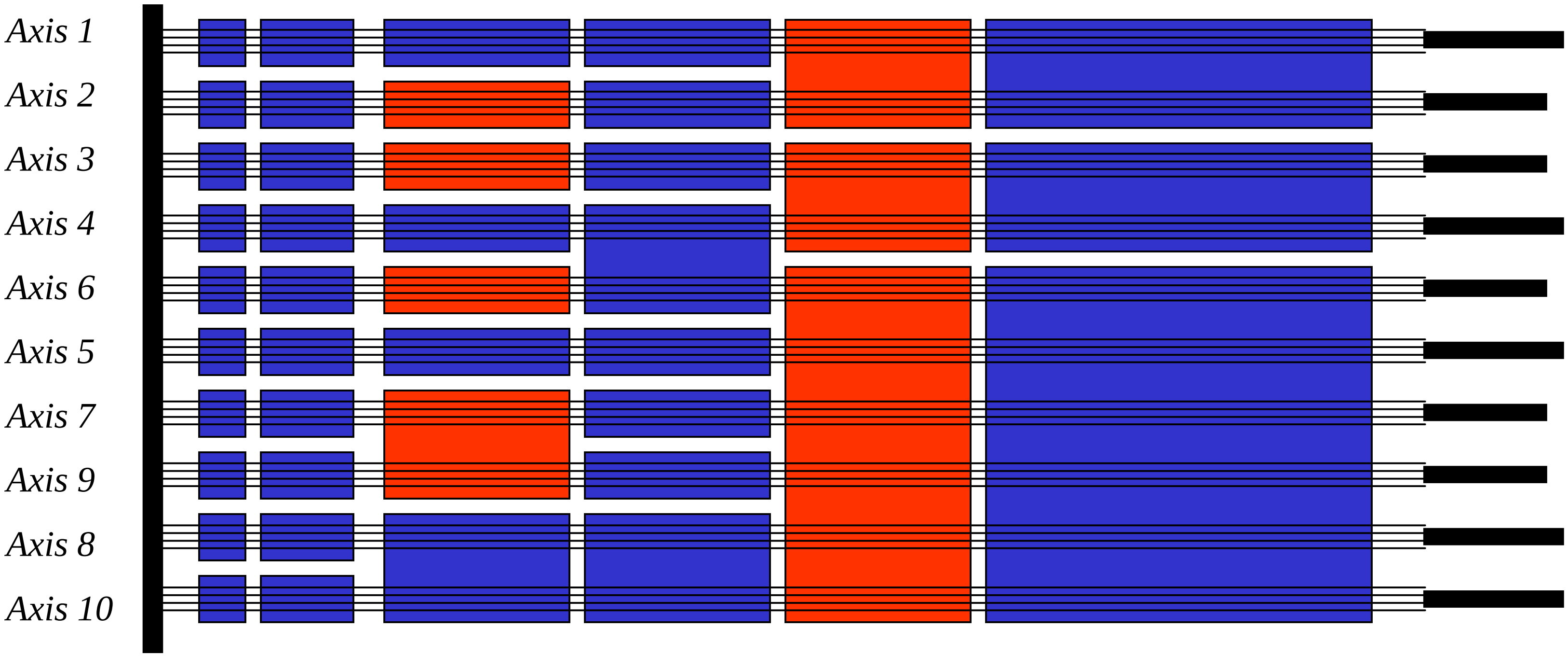

OPEN
SURVEY
ENVELOPE
BALL GRIP
FIST GRIP
PINCH 1
PINCH 2
PINCH 3
POINT
WRITE

Two-dimensional segmentation of multi-axis SMA actuator system on Peltier pellet bed

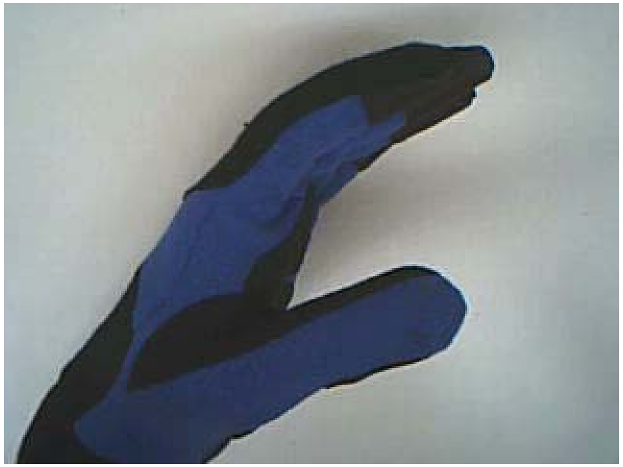


OPEN

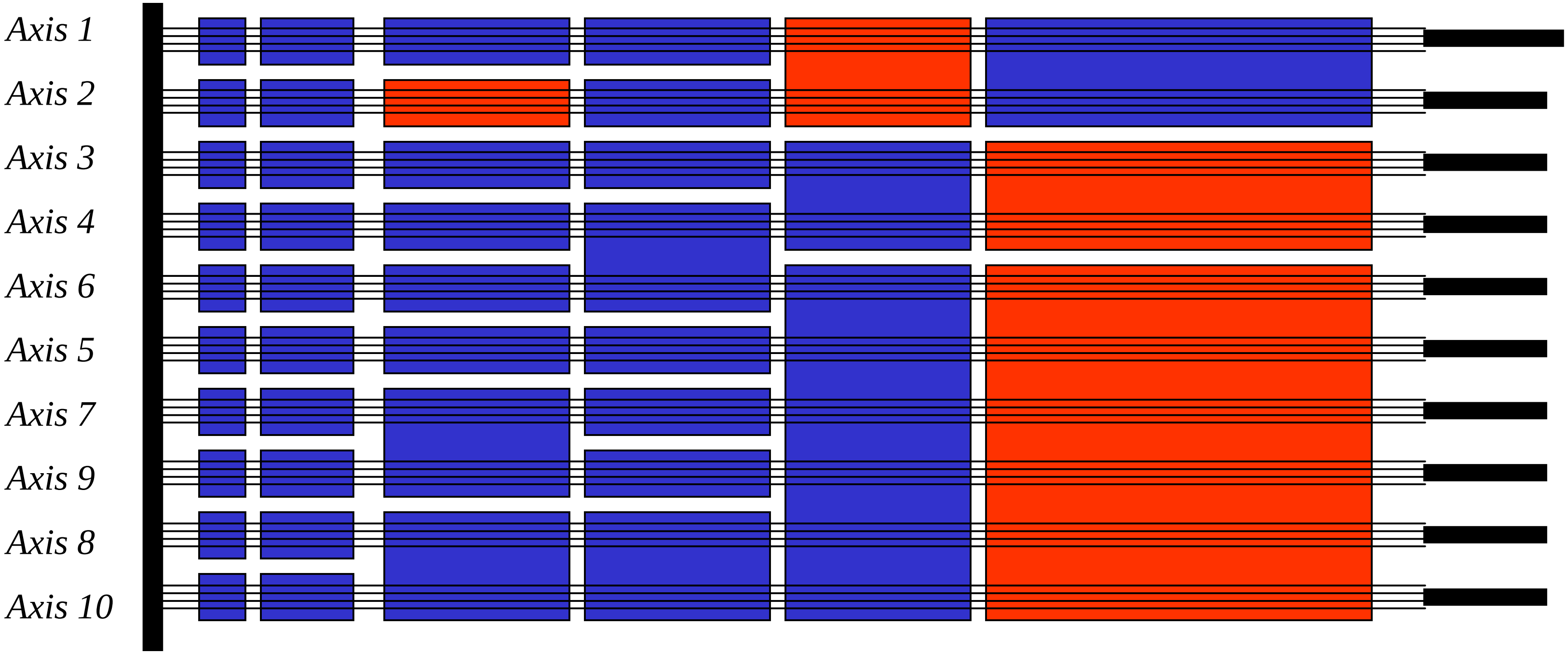
Two-dimensional segmentation of multi-axis SMA actuator system on Peltier pellet bed



SURVEY

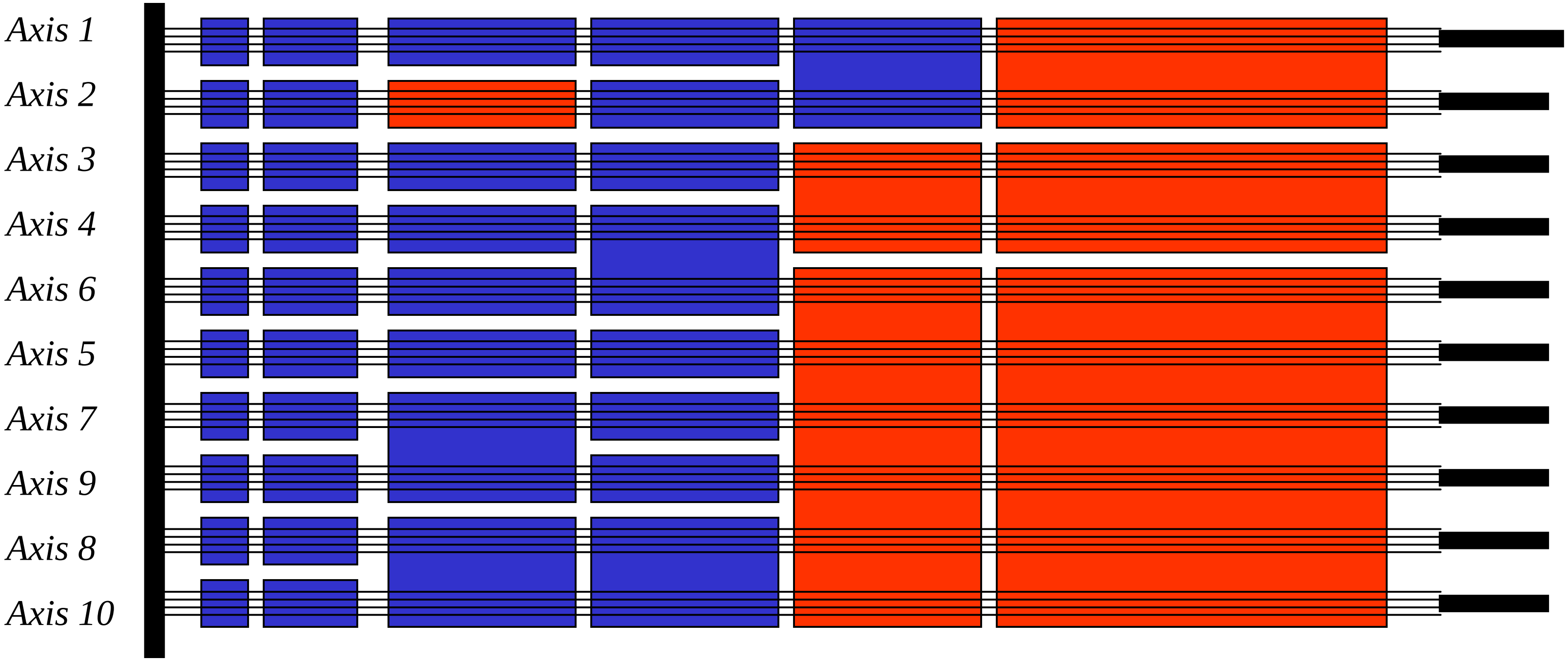


Two-dimensional segmentation of multi-axis SMA actuator system on Peltier pellet bed

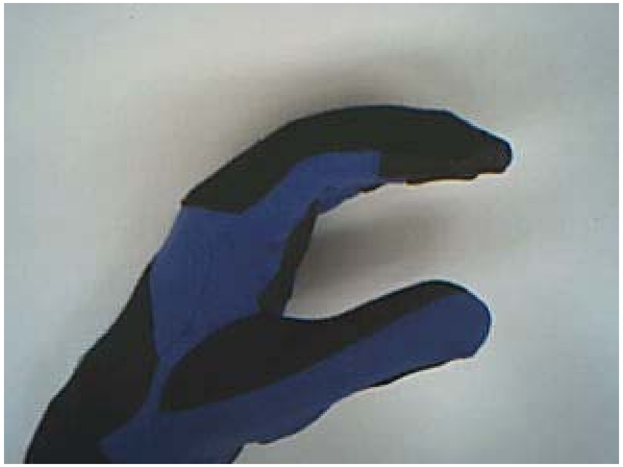


ENVELOPE1

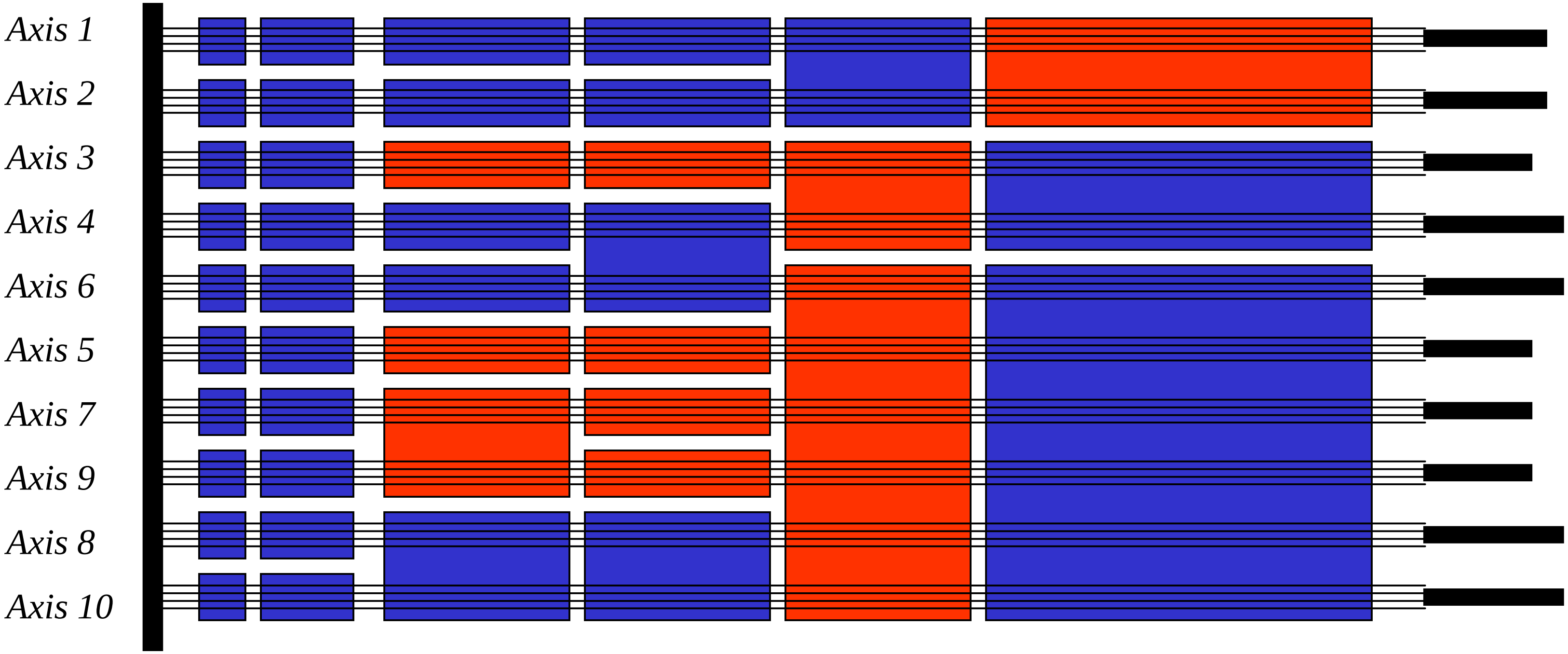
Two-dimensional segmentation of multi-axis SMA actuator system on Peltier pellet bed



ENVELOPE2

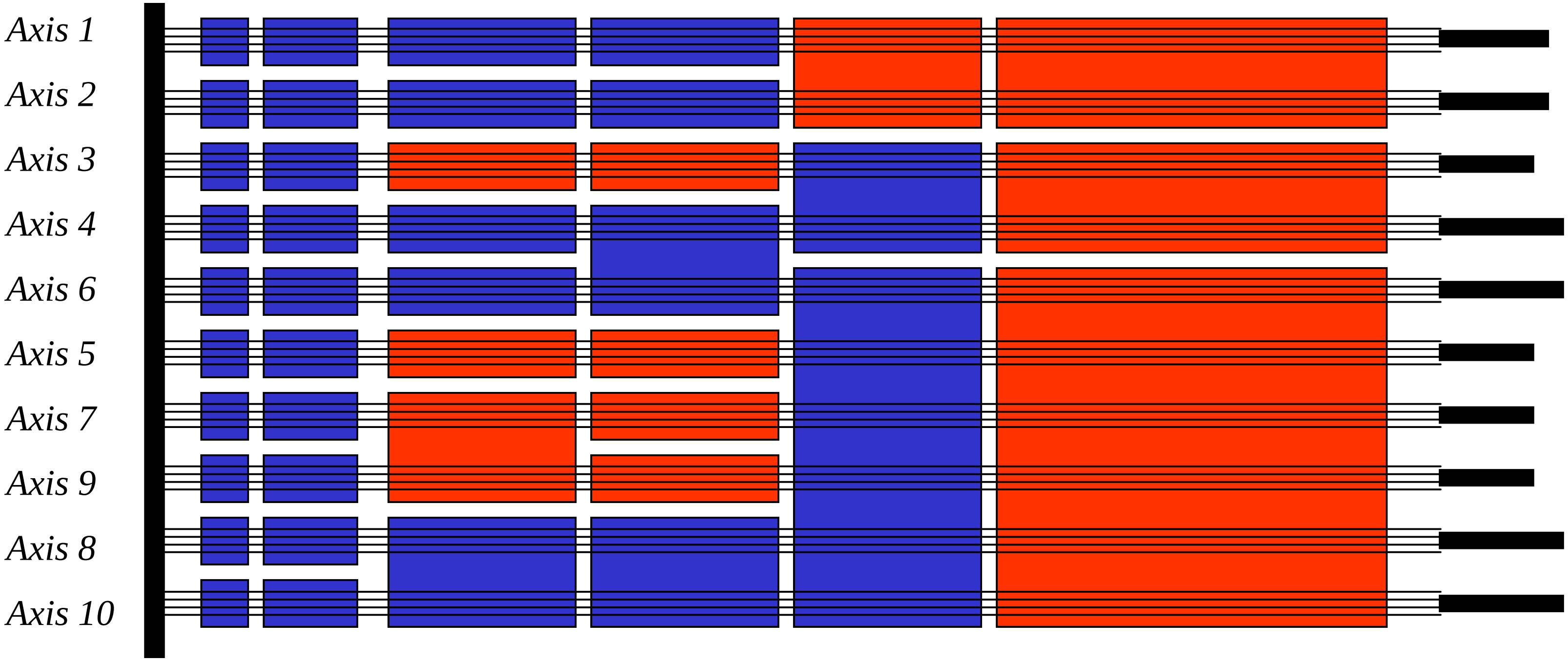


Two-dimensional segmentation of multi-axis SMA actuator system on Peltier pellet bed



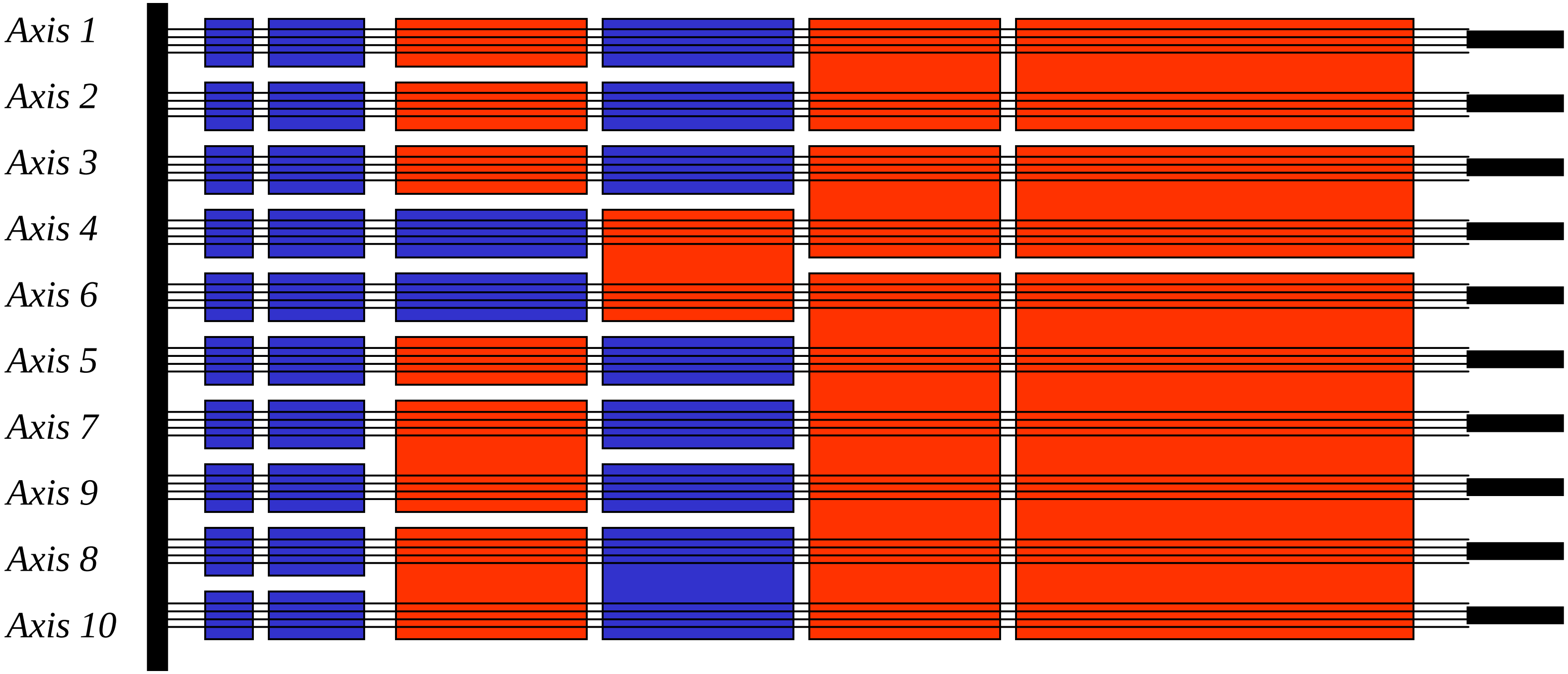
BALL GRIP1

Two-dimensional segmentation of multi-axis SMA actuator system on Peltier pellet bed

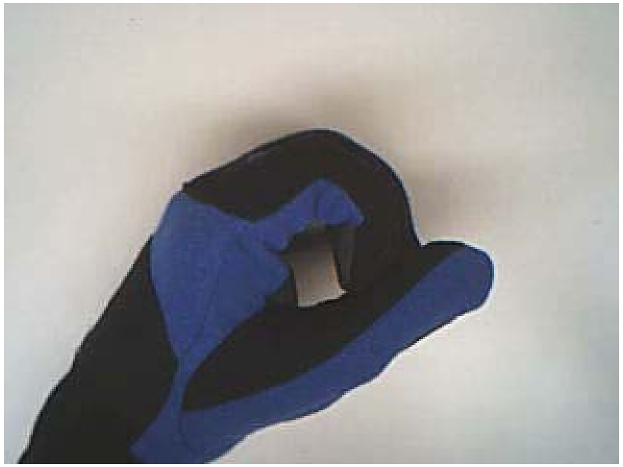


BALL GRIP2

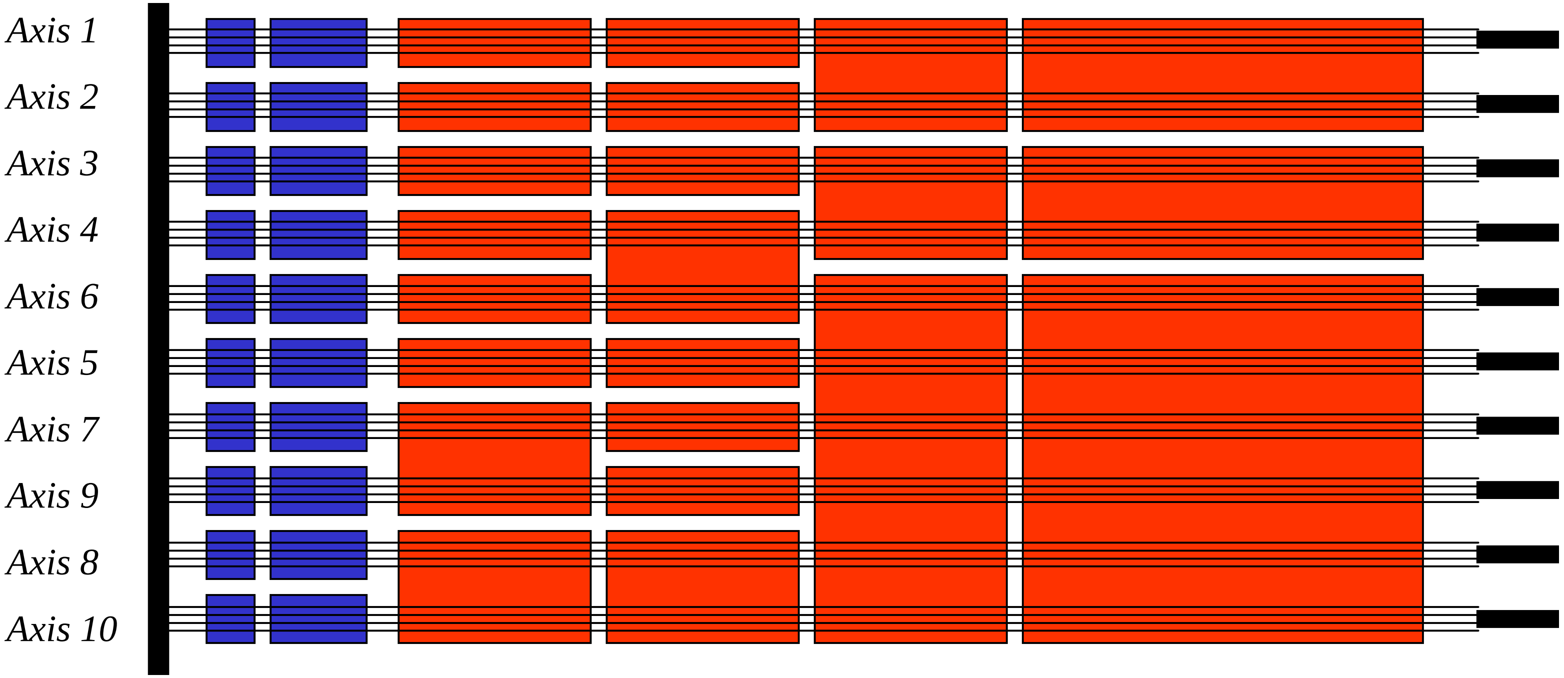
Two-dimensional segmentation of multi-axis SMA actuator system on Peltier pellet bed



FIST GRIP1

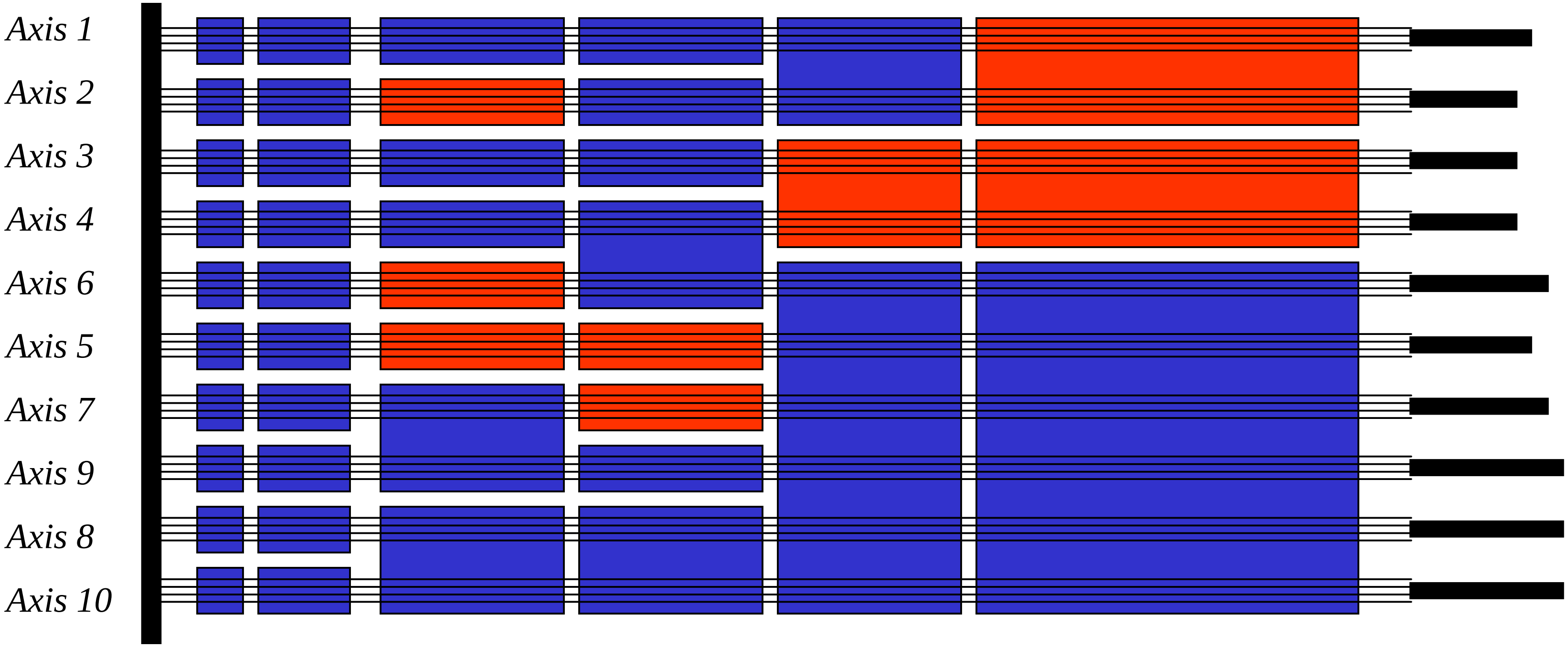


Two-dimensional segmentation of multi-axis SMA actuator system on Peltier pellet bed



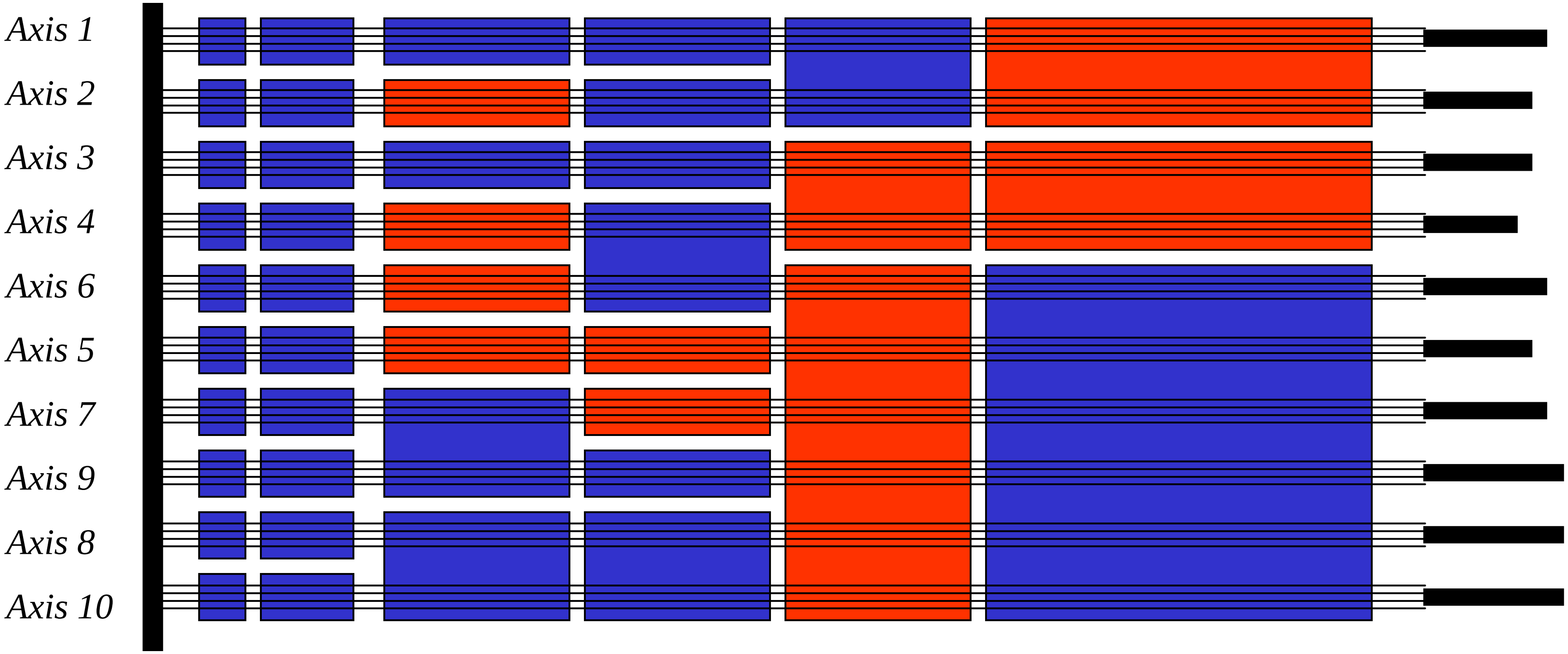
FIST GRIP2

Two-dimensional segmentation of multi-axis SMA actuator system on Peltier pellet bed



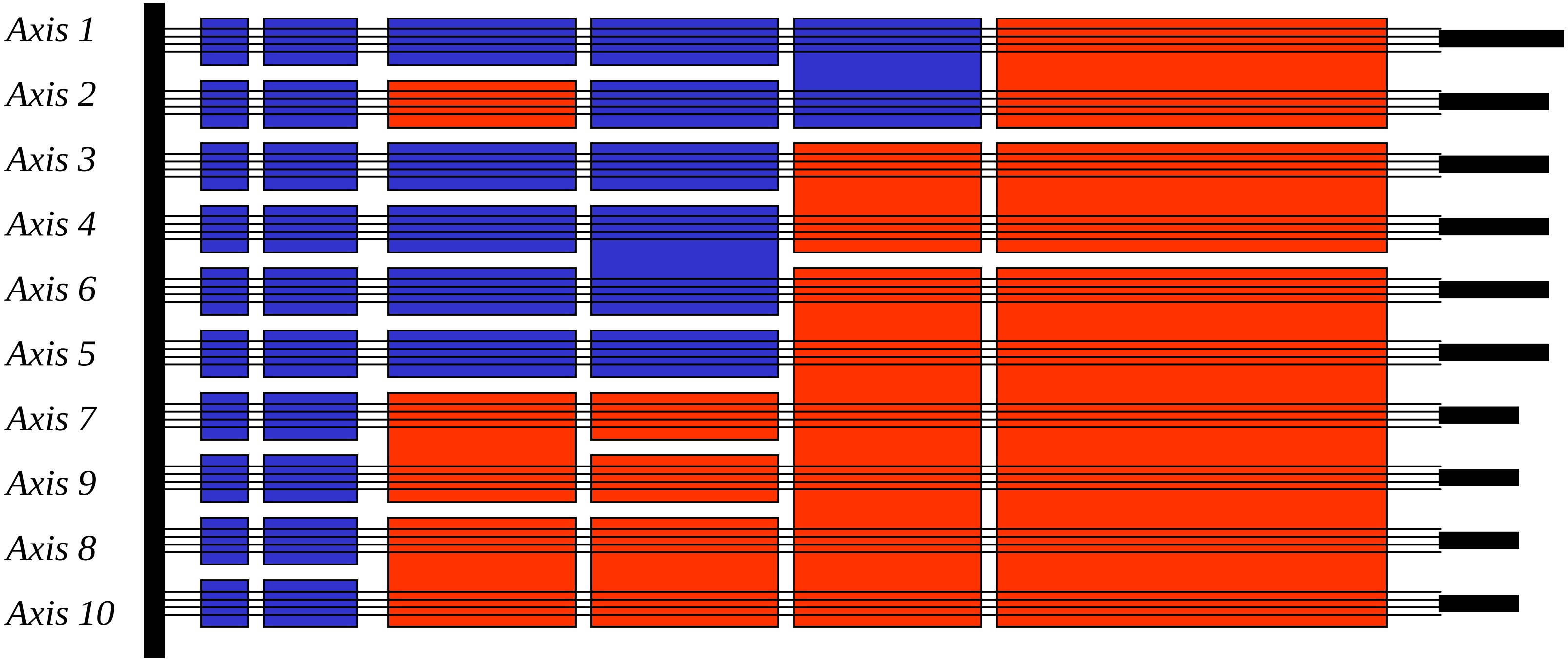
PINCH1-1

Two-dimensional segmentation of multi-axis SMA actuator system on Peltier pellet bed



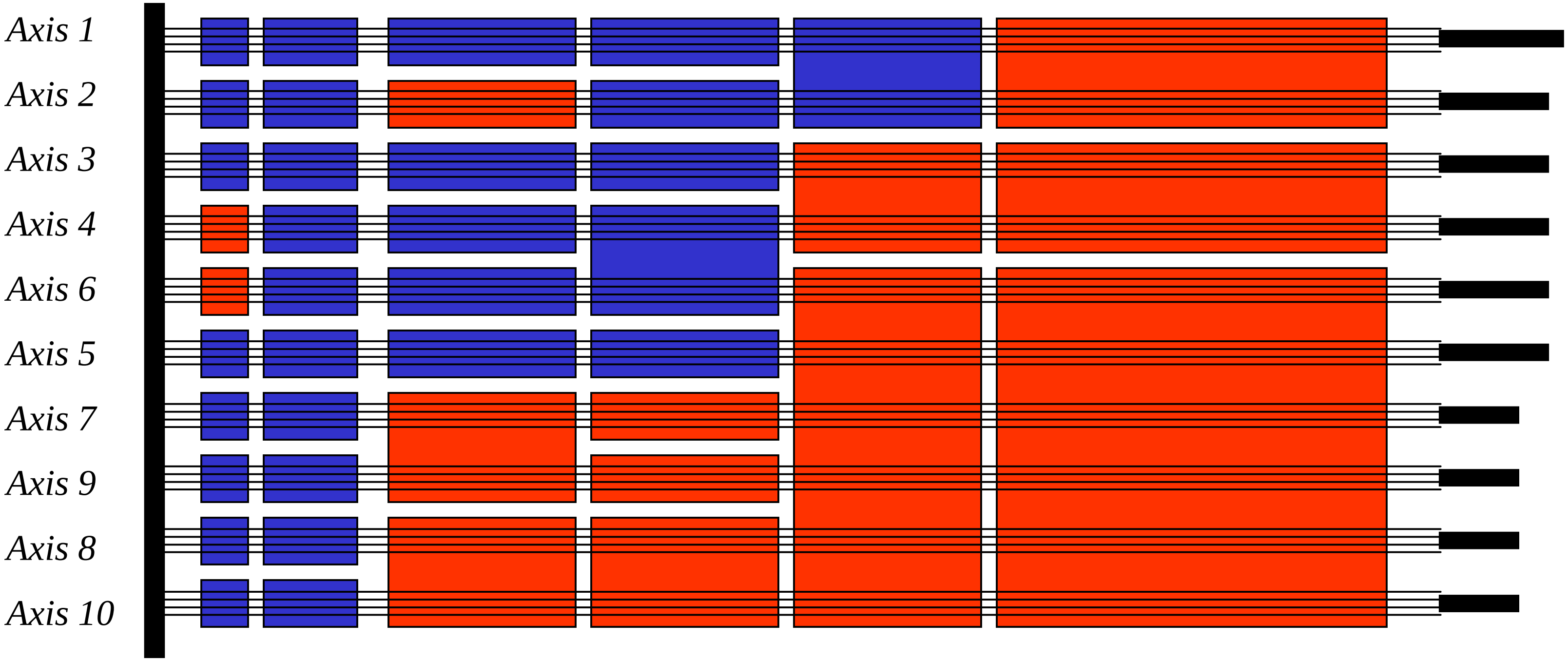
PINCH1-2

Two-dimensional segmentation of multi-axis SMA actuator system on Peltier pellet bed



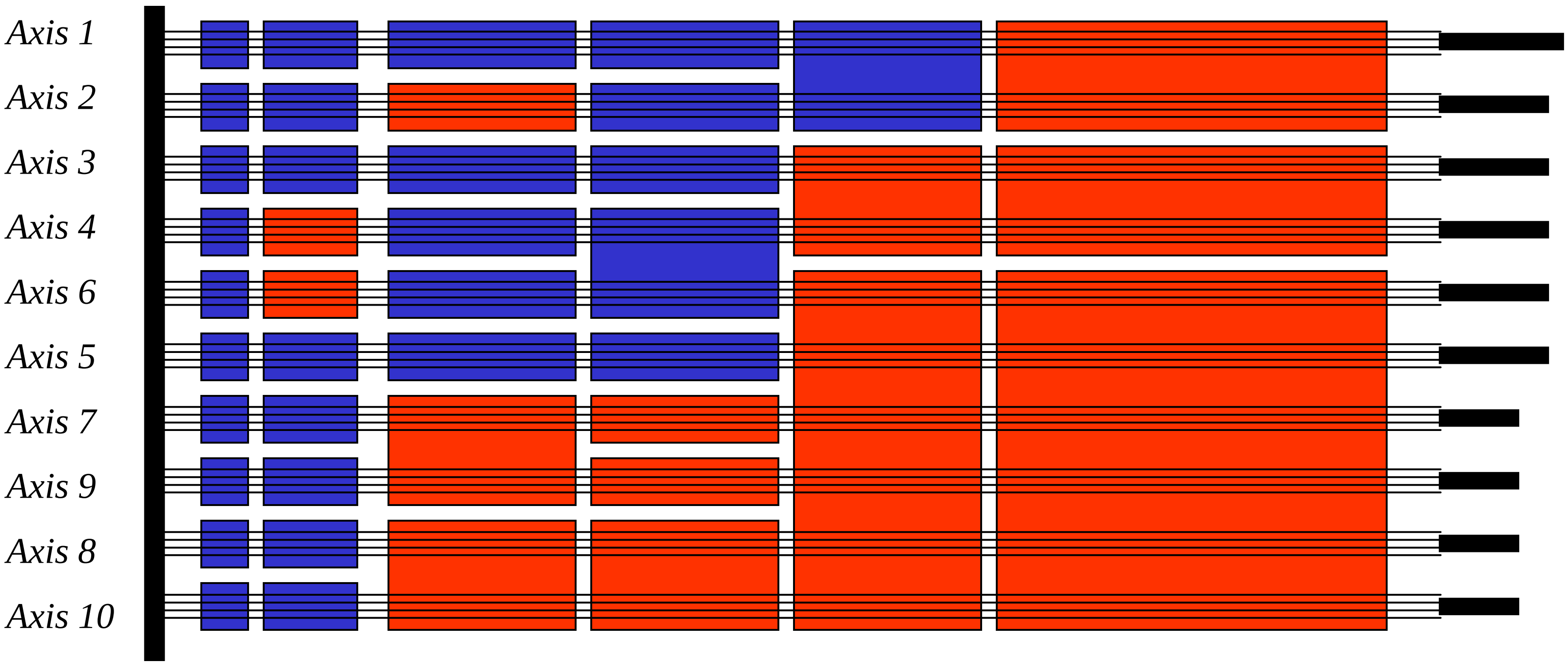
PINCH2-1

Two-dimensional segmentation of multi-axis SMA actuator system on Peltier pellet bed



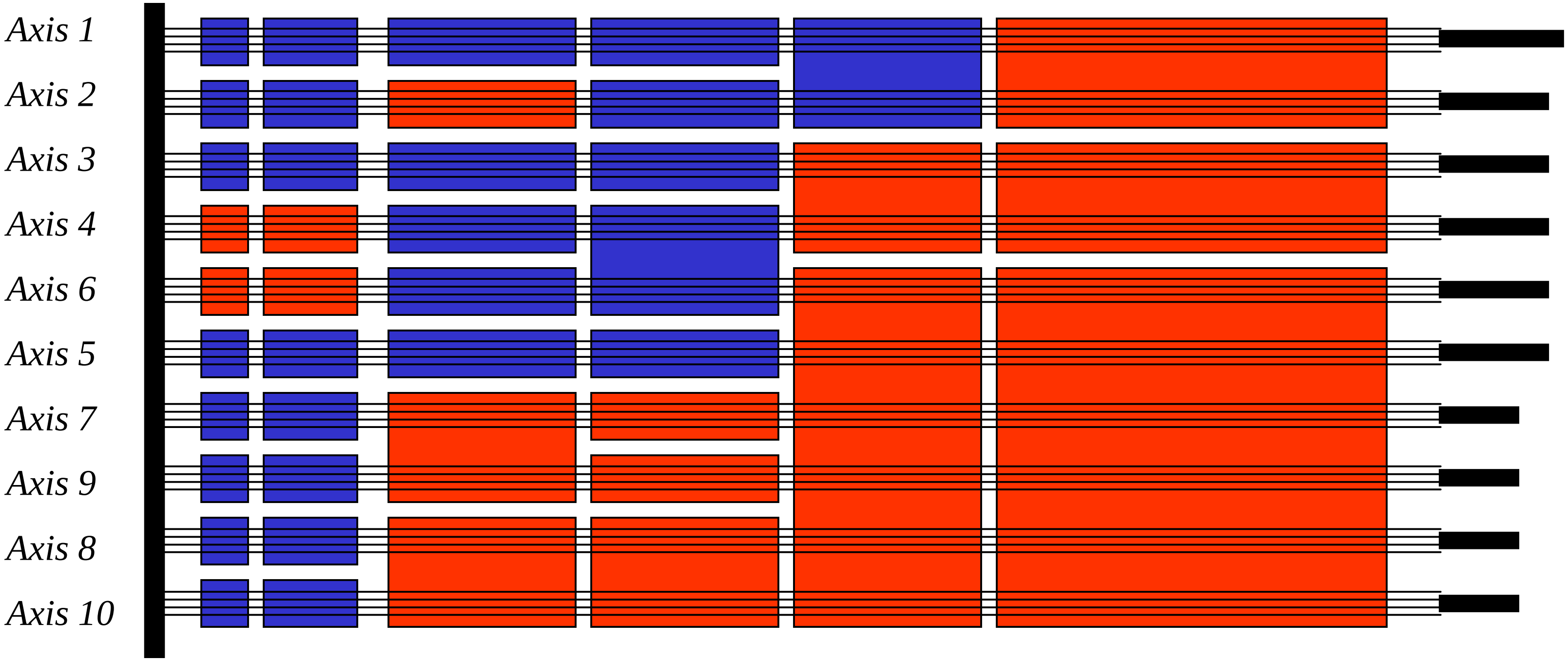
PINCH2-2.25

Two-dimensional segmentation of multi-axis SMA actuator system on Peltier pellet bed

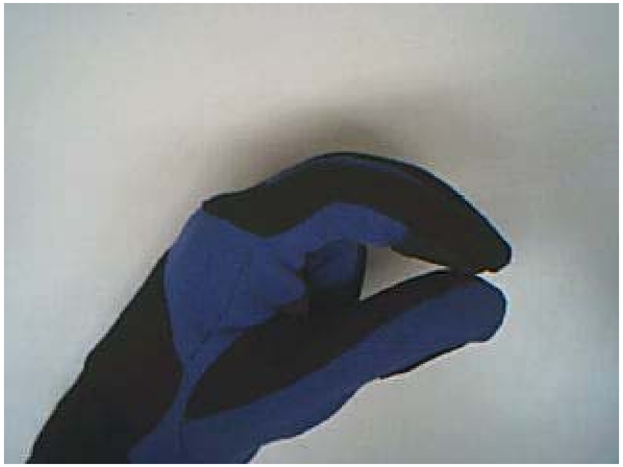


PINCH2-2.5

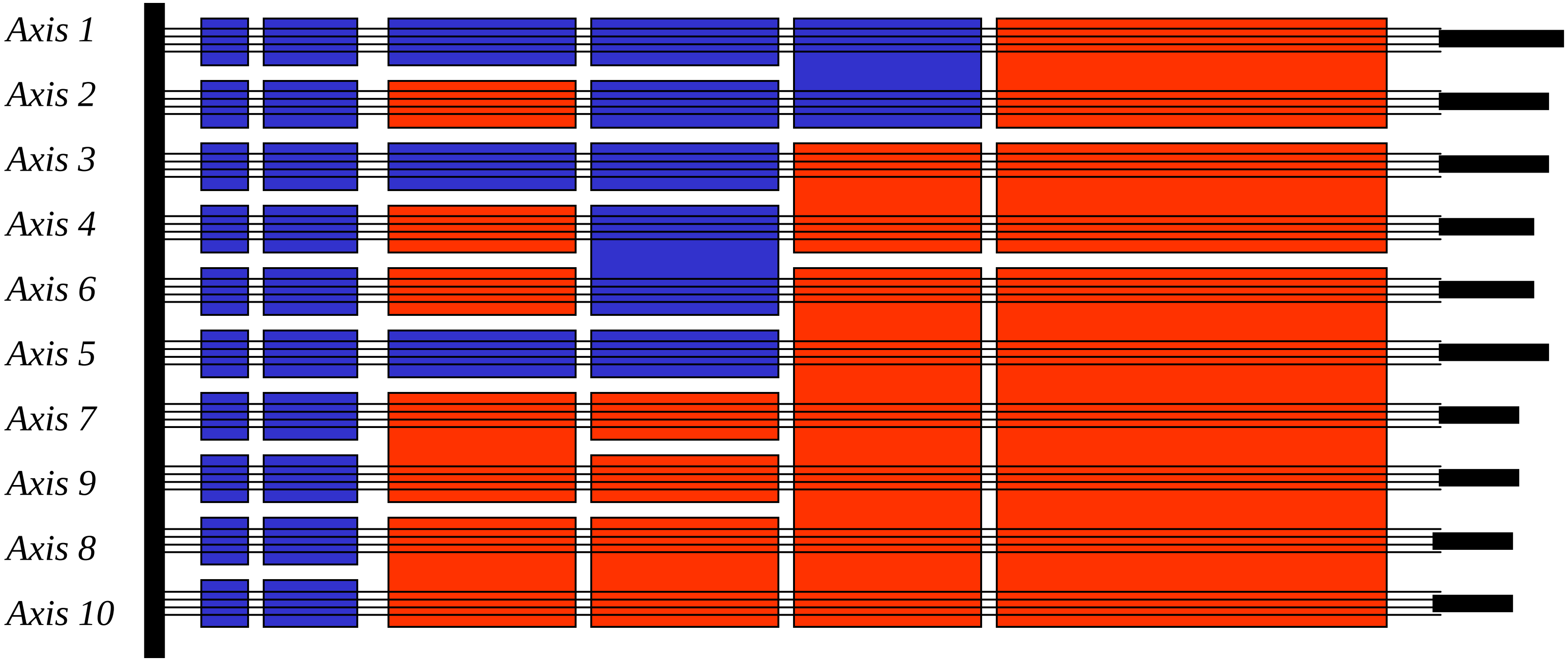
Two-dimensional segmentation of multi-axis SMA actuator system on Peltier pellet bed



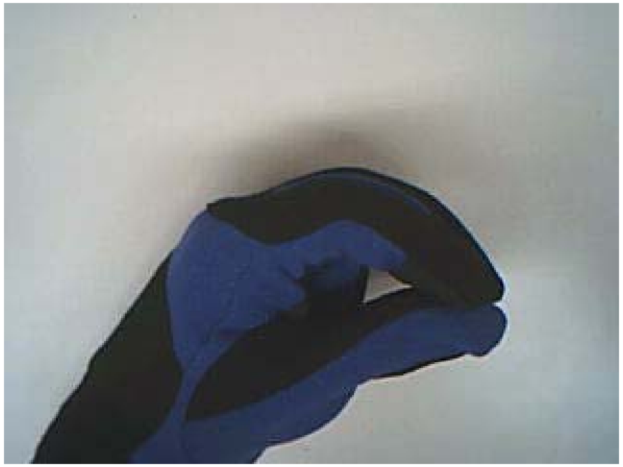
PINCH2-2.75



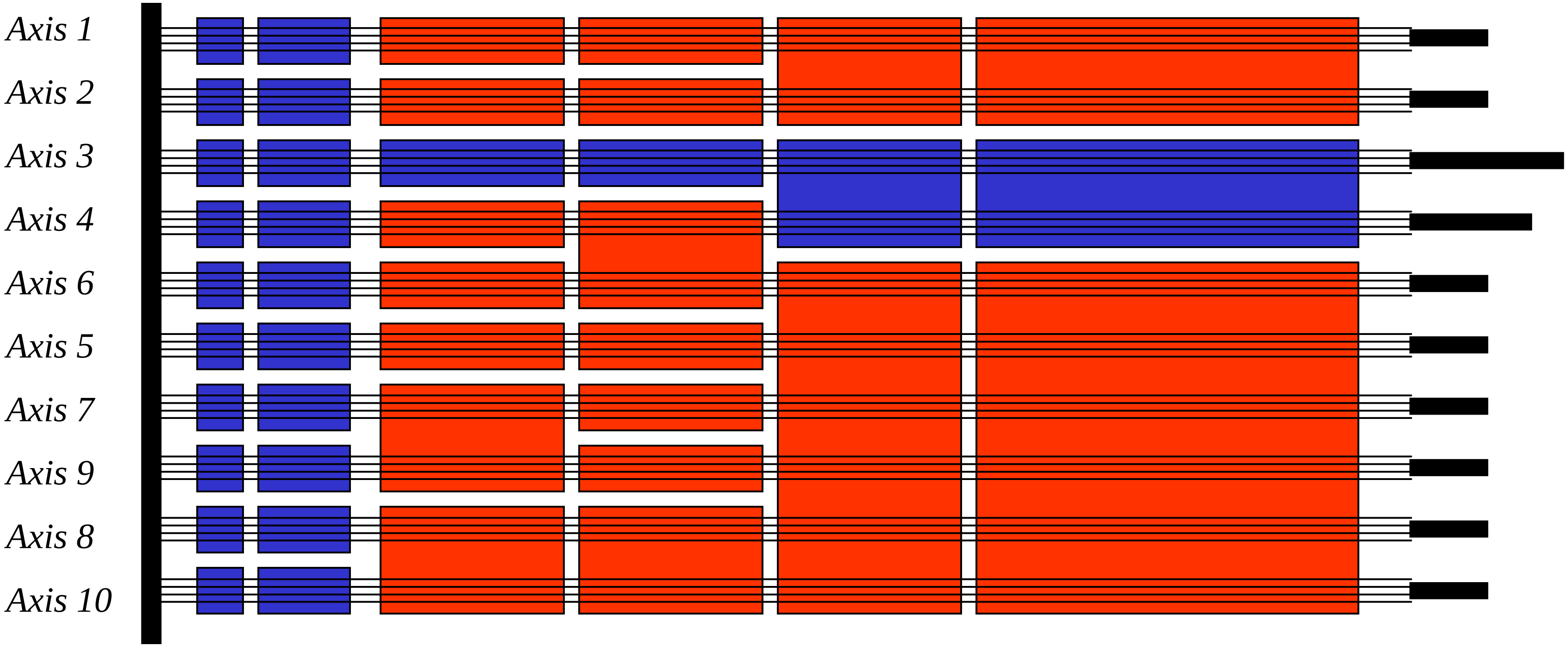
Two-dimensional segmentation of multi-axis SMA actuator system on Peltier pellet bed



PINCH2-3

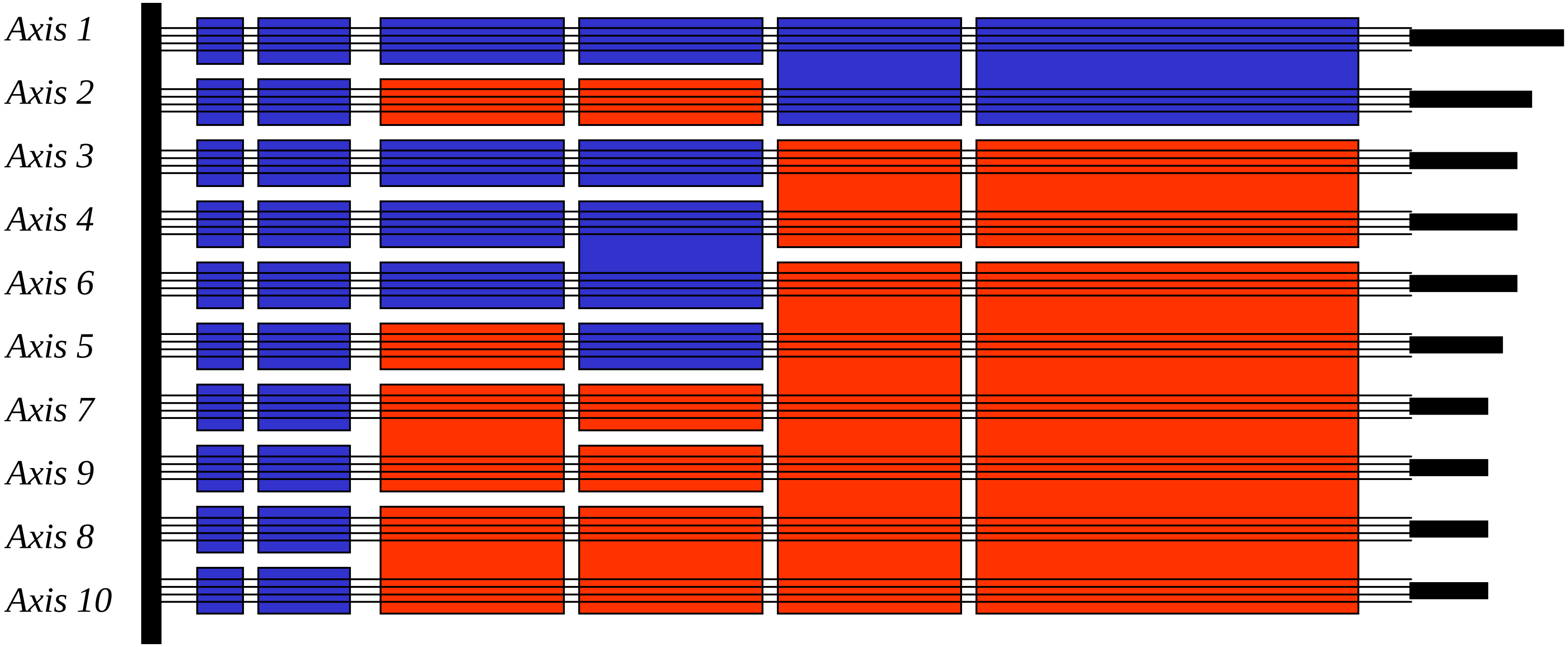


Two-dimensional segmentation of multi-axis SMA actuator system on Peltier pellet bed

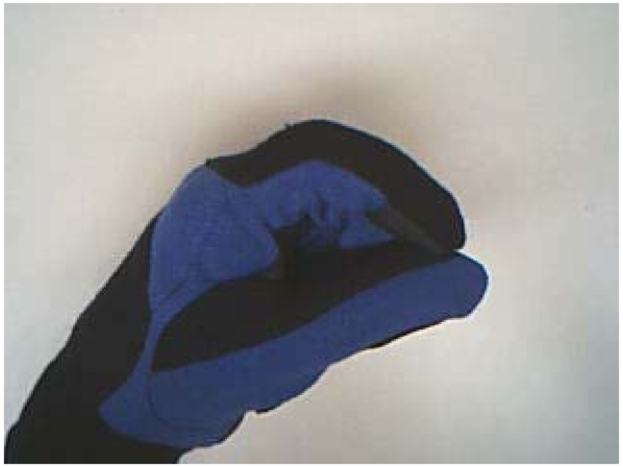


POINT

Two-dimensional segmentation of multi-axis SMA actuator system on Peltier pellet bed



WRITE



Approach

- Think big!

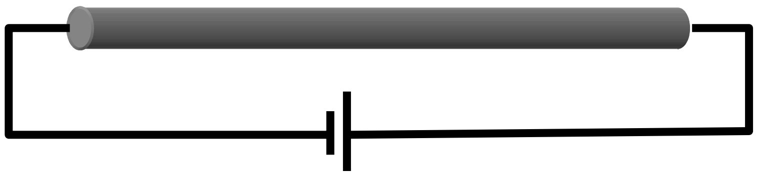
  A vast number of DOF streamlined
- Think small!

  Control of small building blocks
- Think simple!

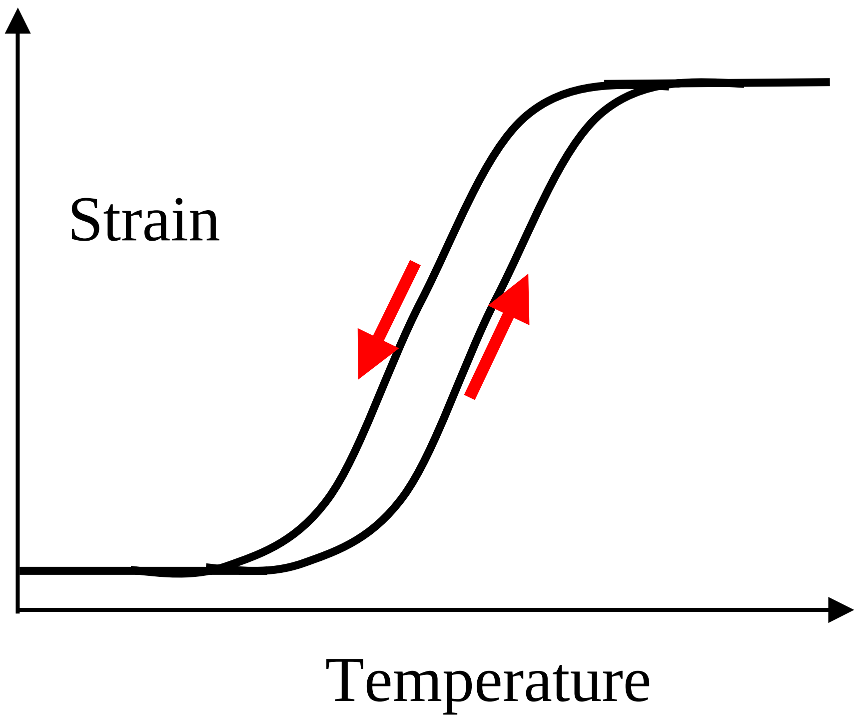
  Chirikjian’s binary actuation paradigm
- Think flexible!

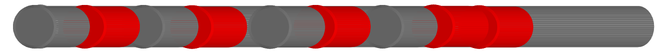
  Field programmable: Reconfigurable robots

Paradox: Nonlinearity is desirable for SBC.

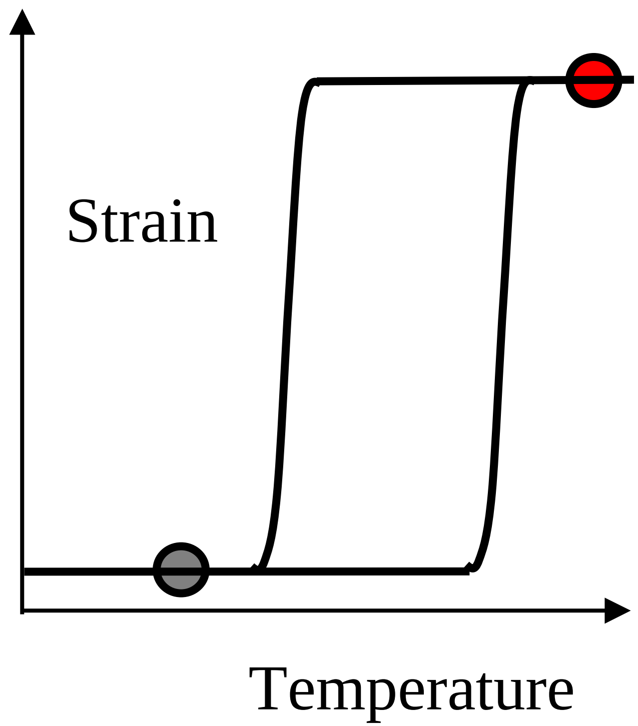


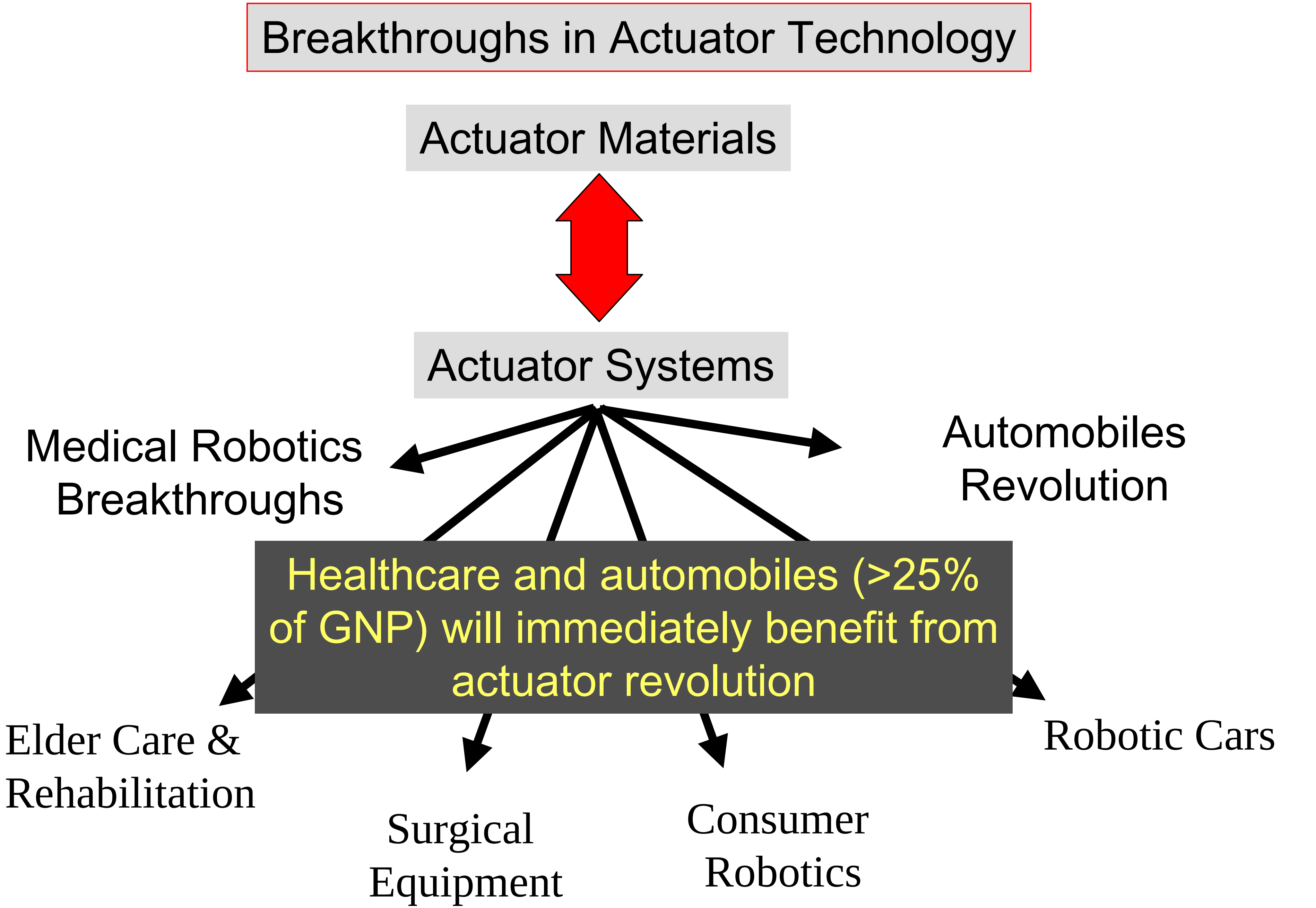
Materials people think that linear characteristics are necessary.





But, what we want for SBC is more nonlinear characteristics.




Breakthroughs in Actuator Technology
Actuator Materials
Actuator Systems
Medical Robotics Breakthroughs
Automobiles Revolution
Healthcare and automobiles (>25% of GNP) will immediately benefit from actuator revolution
Elder Care & Rehabilitation
Surgical Equipment
Consumer Robotics
Robotic Cars

Funding Opportunities

- NSF "Actuator Initiative"
  - Joint program: Robotics, Civil & Mechanical Systems, Materials, Chemical, Biomedical, Design & Mfg, etc.
- NASA/NSF Science Exploration Grand Challenges
  - Including NSF Science and NSF Engineering Dir.
  - Actuators+Battery+Co-Generation: A focal point
- DoD Actuator Technology Development
  - MURI: Multi-disciplinary program

Vision, Strategic Planning, and Roadmap