Autonomous Robotics: Action, Perception and Cognition

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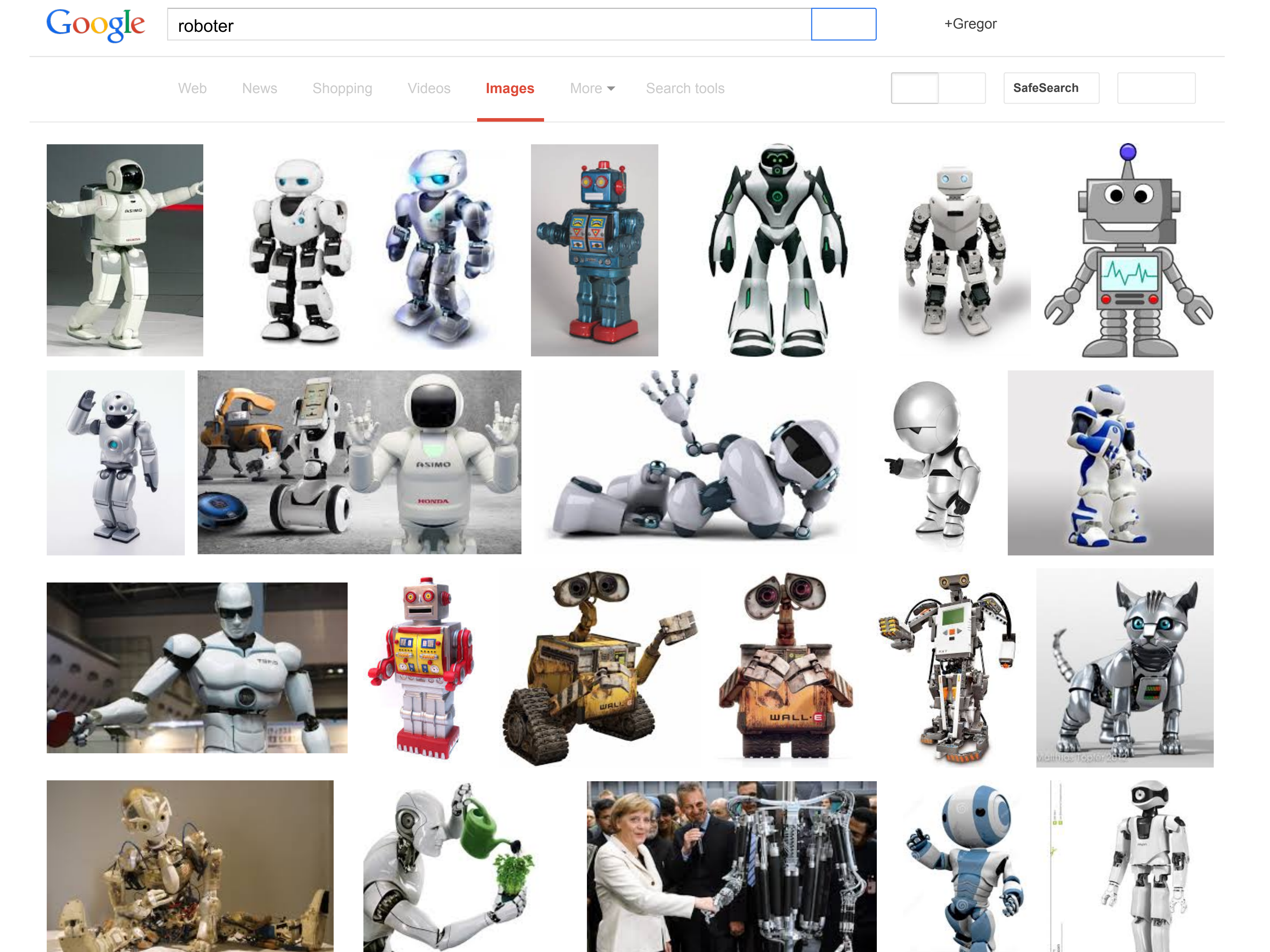
What comes to your mind when you hear the word “robot”

- Google search


Google
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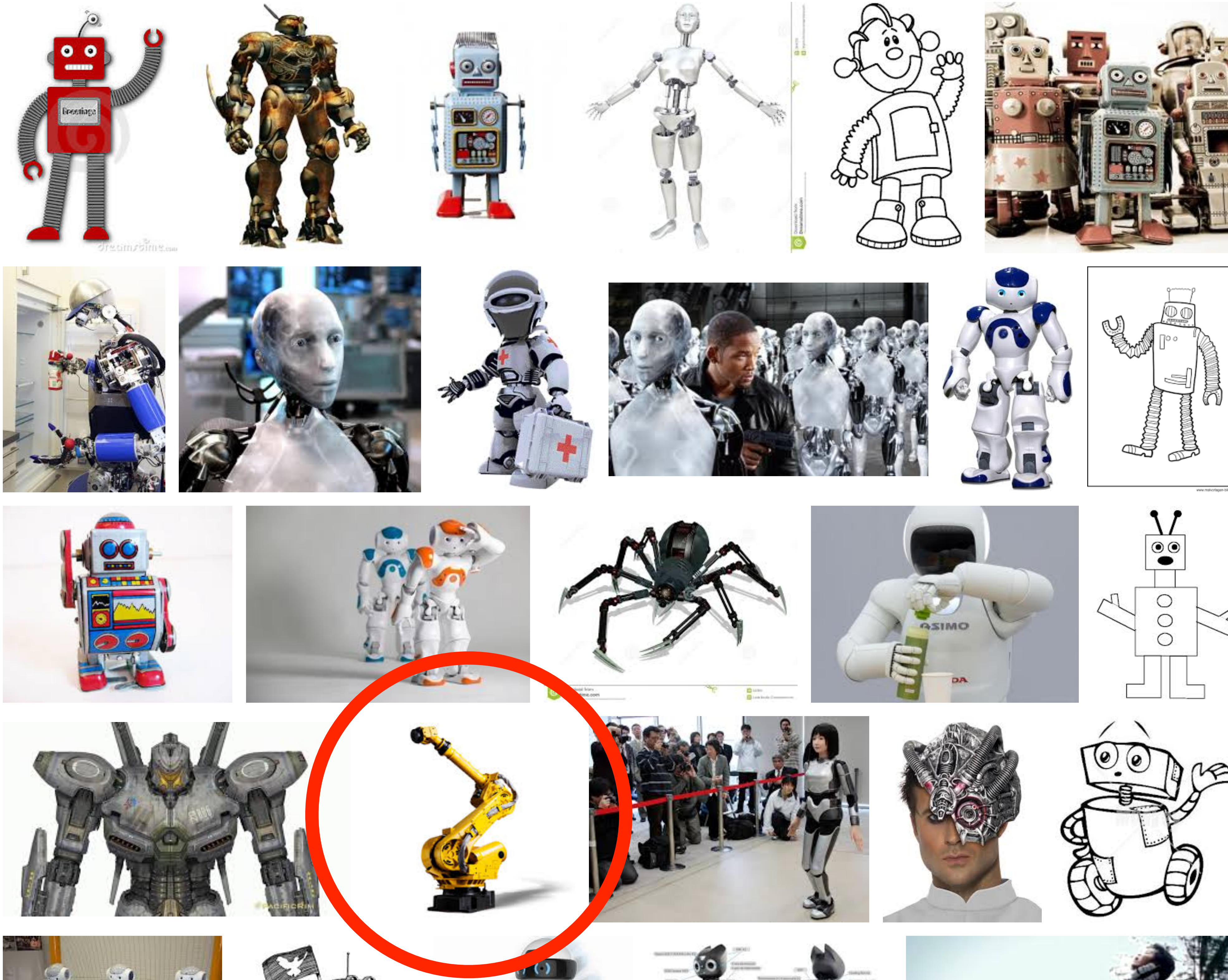
=> Humanoids (or anthropomorphic) robots


ASIMO

industrial robots are actually more common today

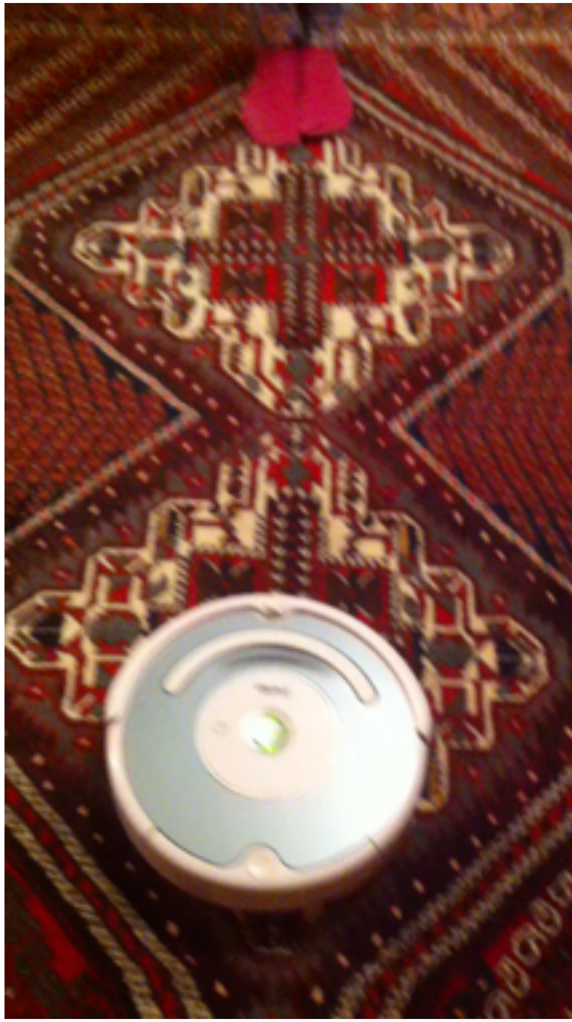
- fundamentally, all factory automization is a form or robotics today: “programmable” machines…

examples of robots

- other than humanoid or industrial

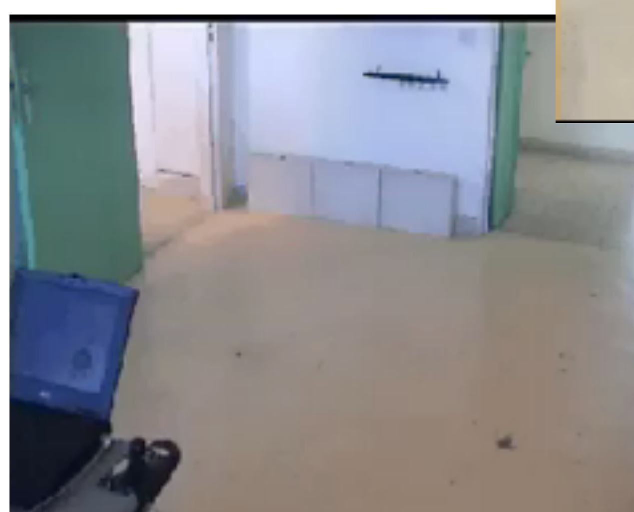
simple, single-task autonomous vehicles

Figure 5.5. Examples of service robots.



[photo credits: WTEC final report 2006]

some of our own autonomous vehicles



outdoor vehicles

(a) (b)

Figure 2.3. Agricultural robotic vehicle (Int Harv, U.S.) (a). Mining haul truck (ACFR, Australia) (b).

Figure 2.1. NASA Mars Rover (NASA Jet Propulsion Laboratory (JPL)).

cars: autonomous driving

legged robots

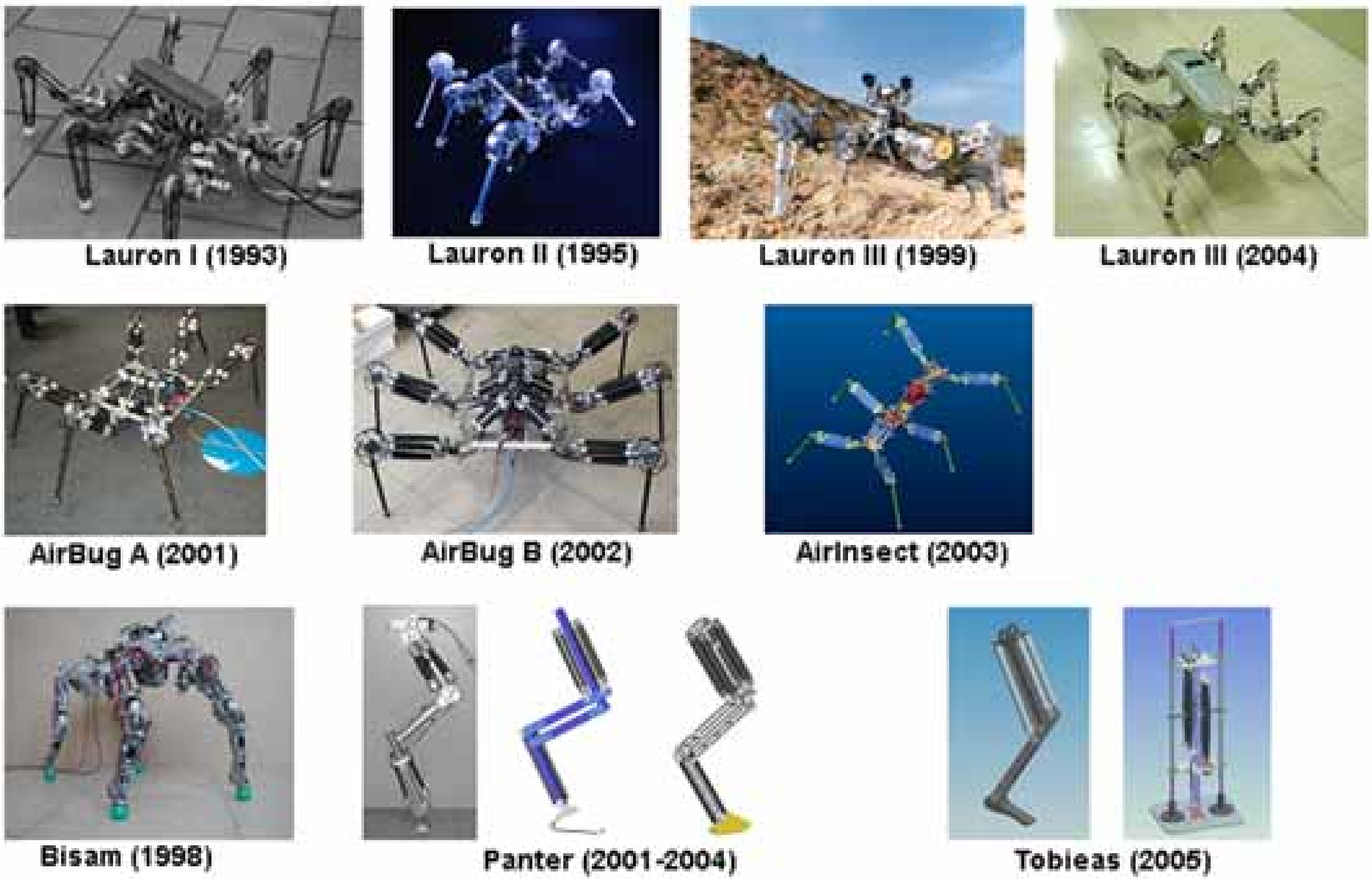


Figure C.58. The walking machines built by Dillmann's group.

snakes, crawlers, climbers

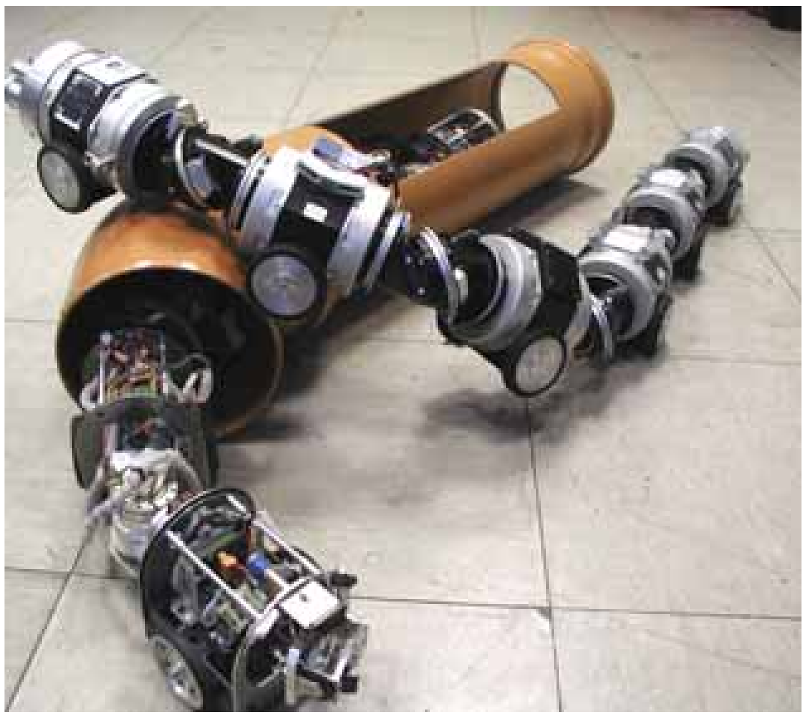


Figure C.57. Inspection robot.

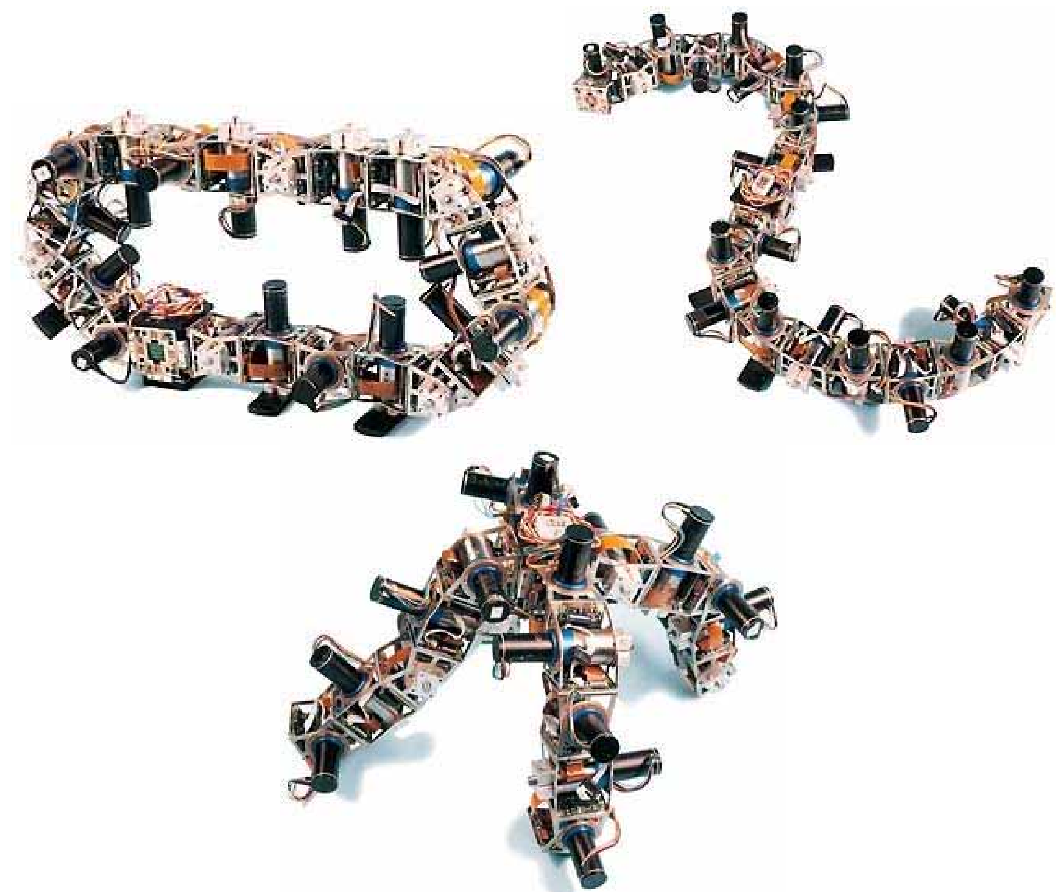


Figure 7.2. Robotic modules can be reconfigured to “morph” into different locomotion systems including wheel-like rolling system (left), a snake-like undulatory locomotion system (right), a four-legged walking system (bottom).

underwater vehicles, ships

Figure 2.2. IFREMER ASTER autonomous underwater vehicle.

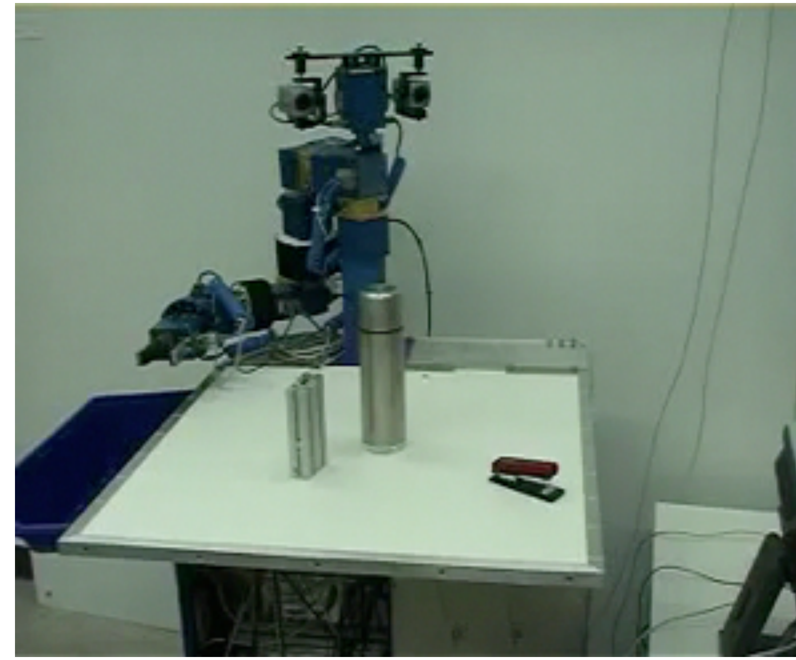
Figure 2.11. HROV (Hybrid ROV) project (Johns Hopkins University (JHU) and Woods Hole (WHOL), U.S.).

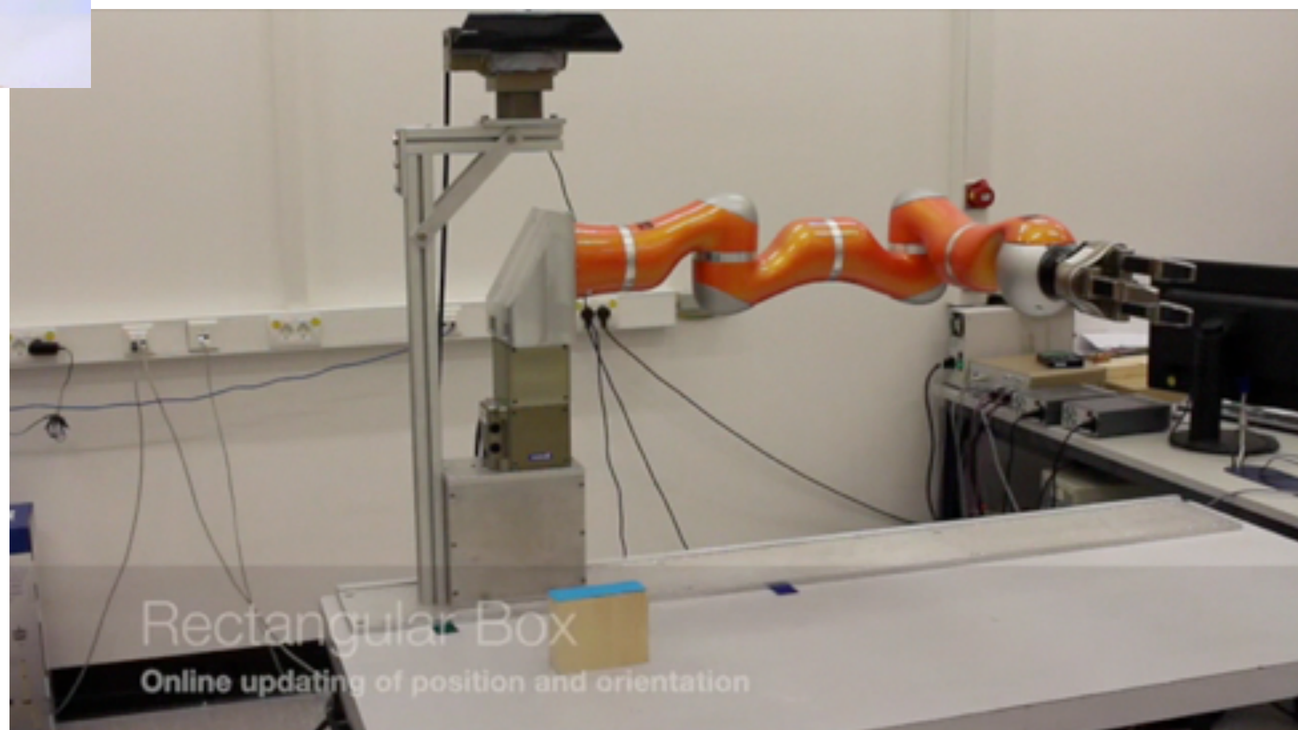
airborne robots

robotic manipulators, hands

Figure 4.10. Dexterous arms at DLR, NASA and UMASS.

some of our own robotic manipulators

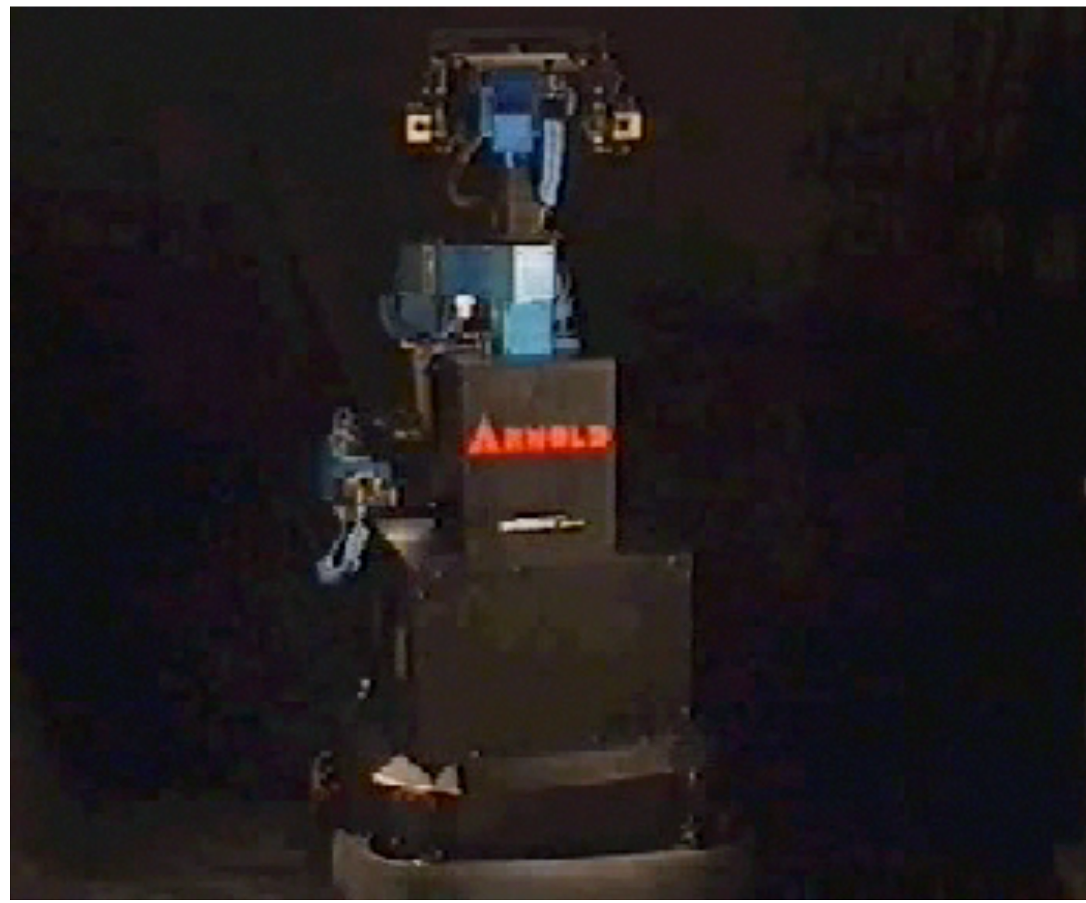




mobile robot manipulators

Figure C.28. Dexterous arm on mobile base, opening door (left), robot passing through doorway (right).

our own mobile robot manipulator



[Arnold: 1998-2000]

autonomous robotics

- *auto-nomos*: giving laws to oneself
- minimally: autonomous robots generate behavior based on sensory information obtained from their own on-board sensors
- in contrast to industrial robots that are programmed in a fixed and detailed way

autonomous robotics

- but: even an industrial robot uses autonomous control to reach its programmed goals…
- => autonomy is expected to go beyond control, include decisions=qualitative change of behavior
  - e.g. avoid obstacle to the left vs. to the right
  - e.g., reach for one object rather than another

autonomous robotics

- but: we do not expect autonomous robots to just do whatever “they want”… we expect to give them “order”

autonomous robotics

- autonomy as a "programming interface":
  - give instructions to a robot at a high level, in regular human language and gesture in a shared environment…
  - … and let the autonomous robot deal with the "details" of how to achieve goals

why autonomous robots?

why autonomous robots?

- asked my 18 year old son…
  - to clean up, to serve drinks
  - but they are just generally cool too..
  - .. (after some hesitation)… in the military

assistance robotics

- at home, in the work place
- collaborate with human users

toy/entertainment/animation

- including therapy (autism)

military, fire fighting, rescue

- the "ideal" application because desire to remove human agent from the scene is consensual …
- much US research

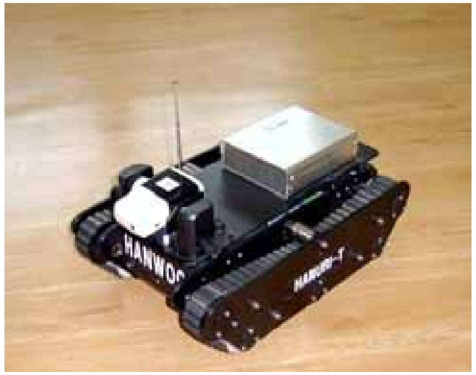
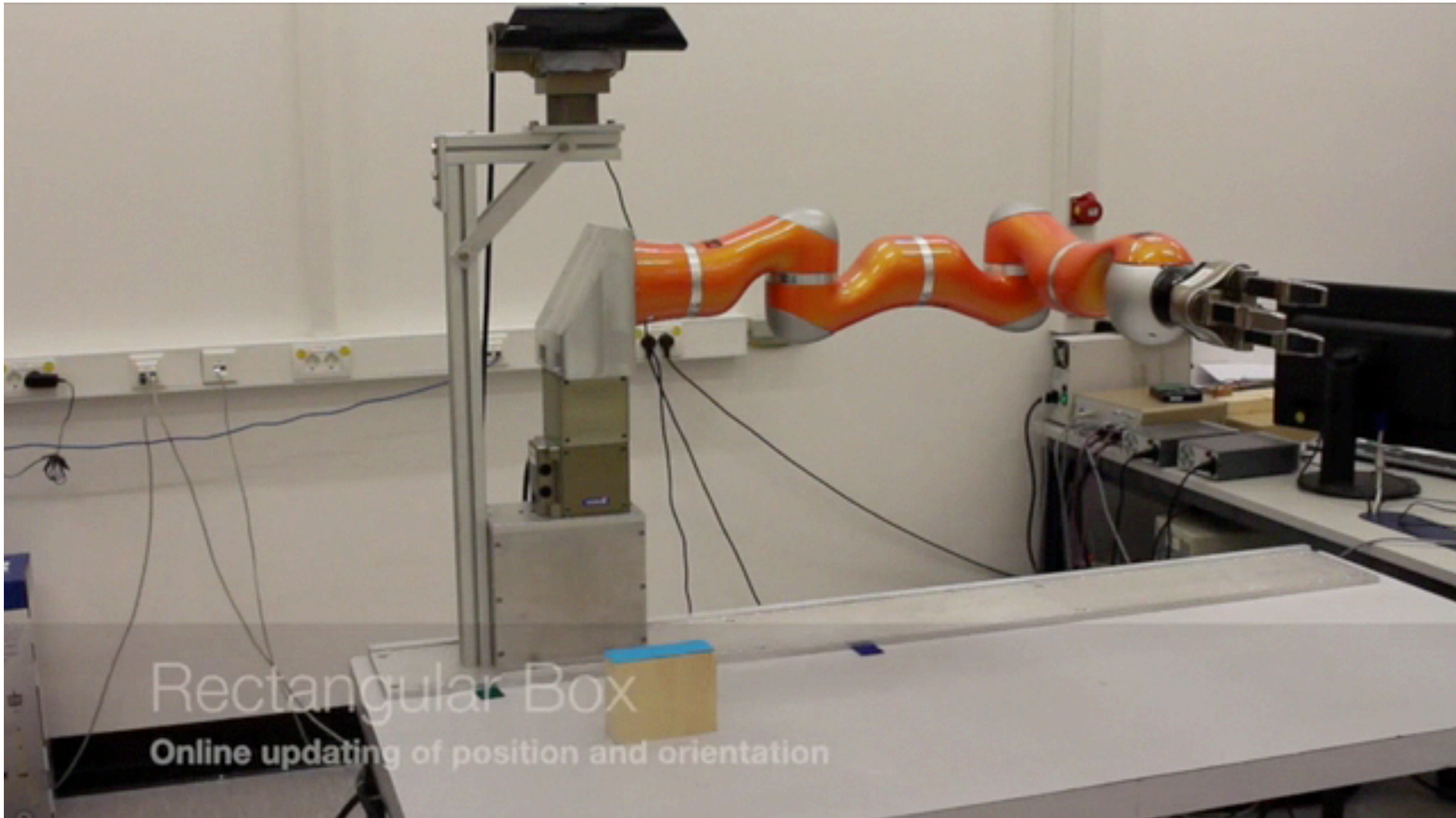


Figure B.11. Military Robot.

(robot ethics…interesting topic)

- may a military robot decide autonomously to shoot
  - …. navy ships do that already…
- may a autonomous car decide between avoiding a pedestrian and preventing danger for car occupants?
  - fundamental problem: off-loading decisions from user to designer …

autonomous robotics as a “playground” of research

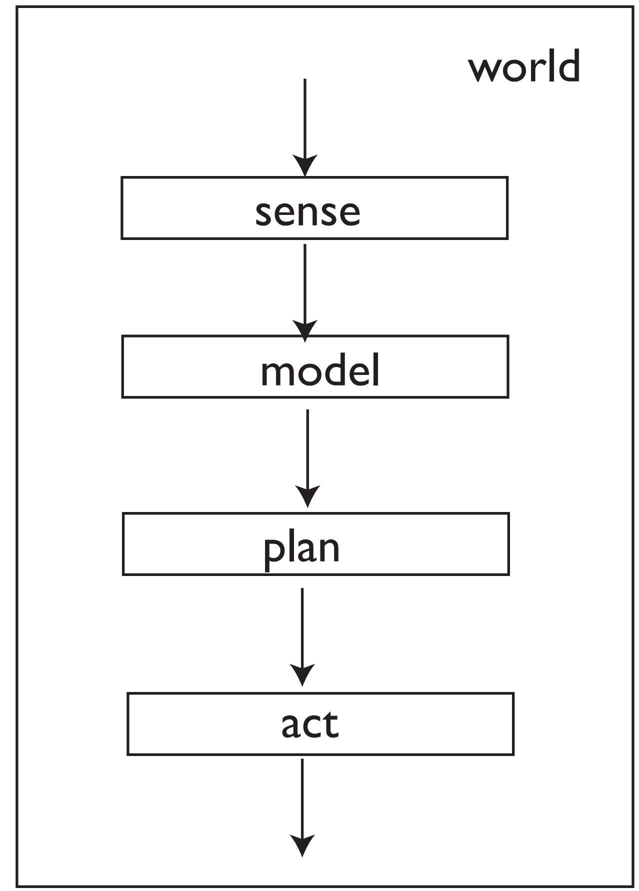


autonomous robotics as a "playground" of research

- modern engineering: model systems, treat remainder stochastically….
  - autonomous robotics: natural environments are difficult to model
- modern engineering: disciplinary
  - autonomous robotics: highly interdisciplinary
- modern engineering: compartmentalized
  - autonomous robotics: requires system integration

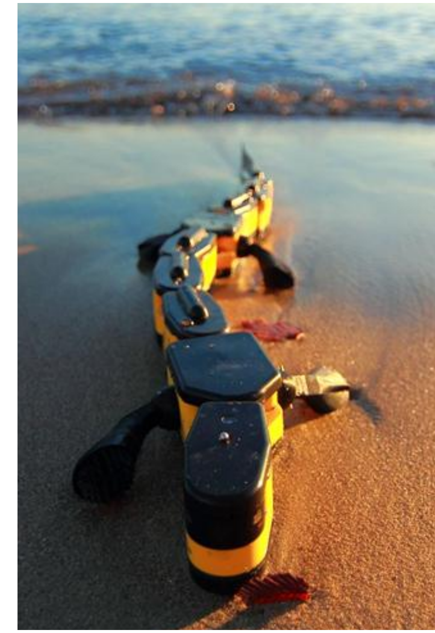
what is entailed in designing an autonomous robot?

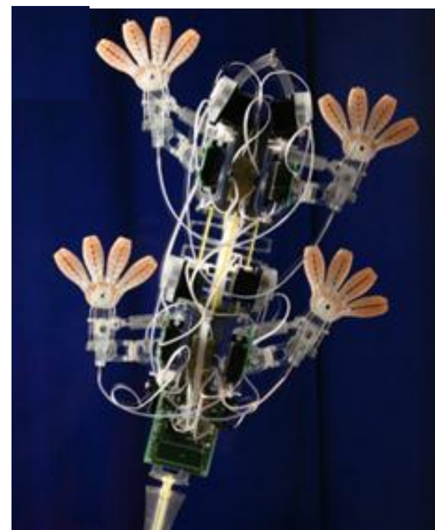
- sensors
- signal processing, digitization
- estimation, detection, classification
- planning, programming, reasoning
- communcation, data security
- optimal control, control
- mechanics, actuators



=> interdisciplinarity

biologically inspired robotics





state of the art: current explosion

- through maturation of technology
- fast computation makes approach real-time that used to be not viable
- laser range finder
- modern software engineering facilitates programming
- … many detailed and specific improvements

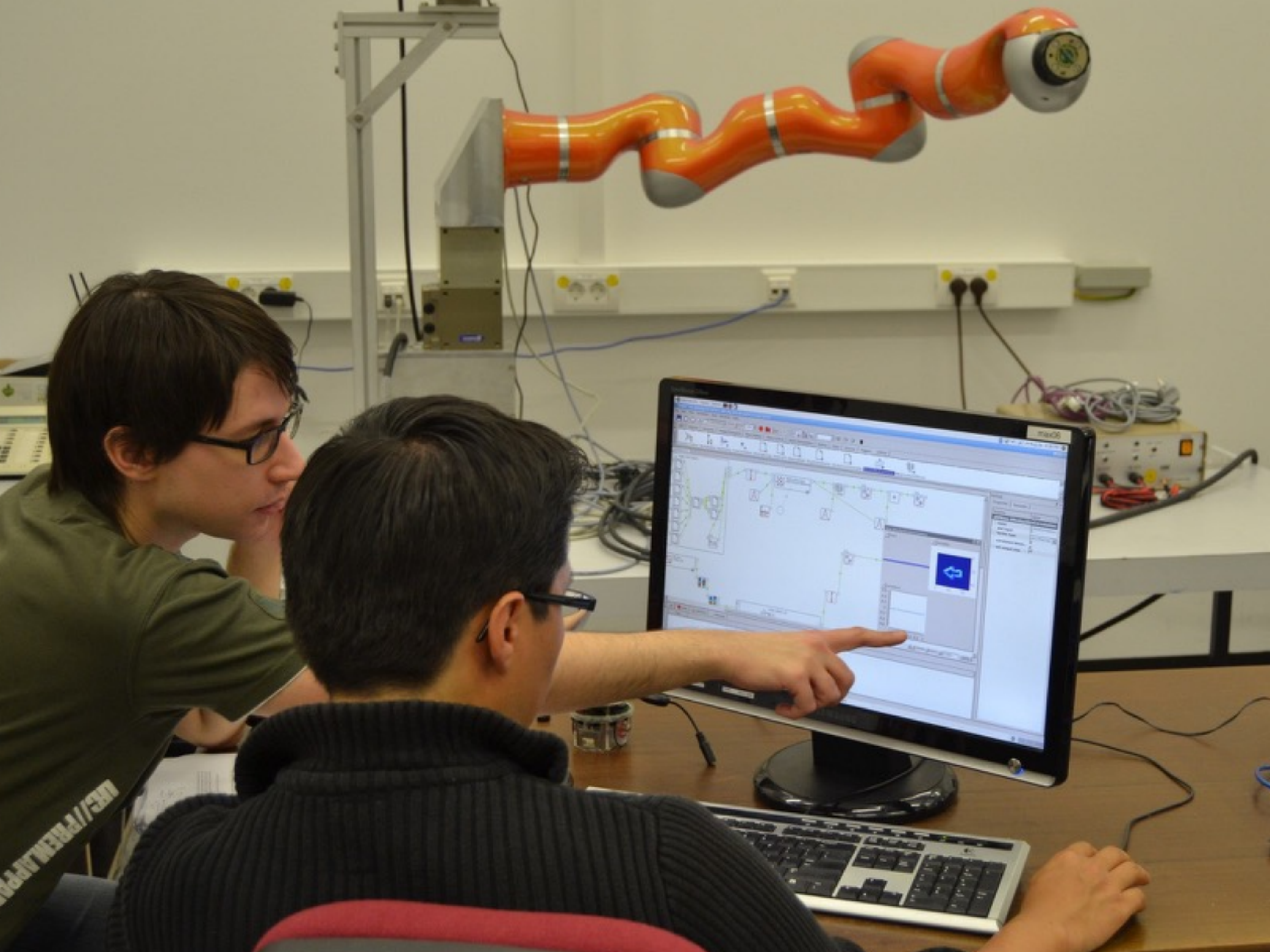
4 core problems/challenges

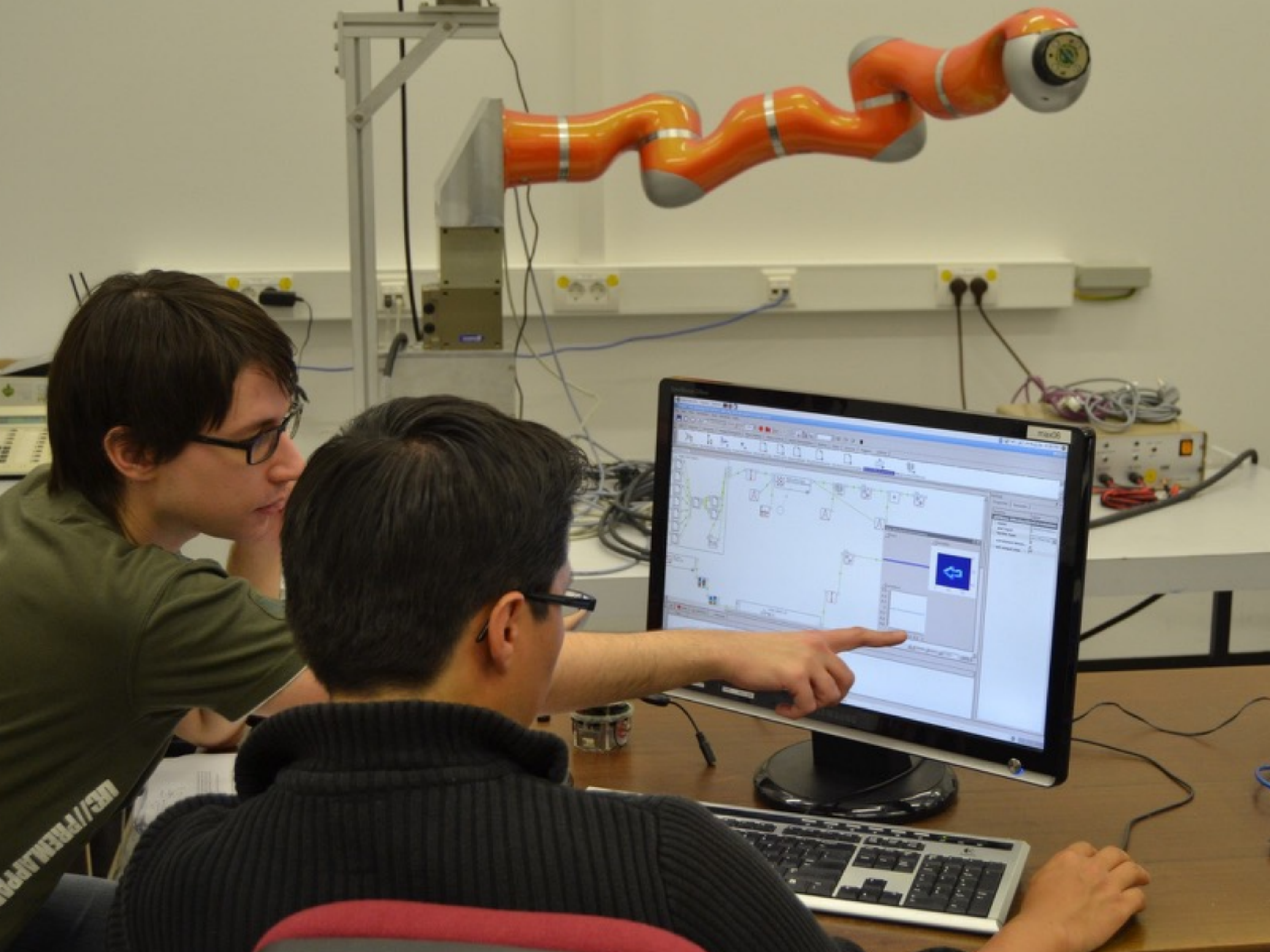
- perception
- interacting with humans
- background knowledge
- movement generation

(1) perception

- no autonomy without perception
- main channel: visual perception

what is perception?



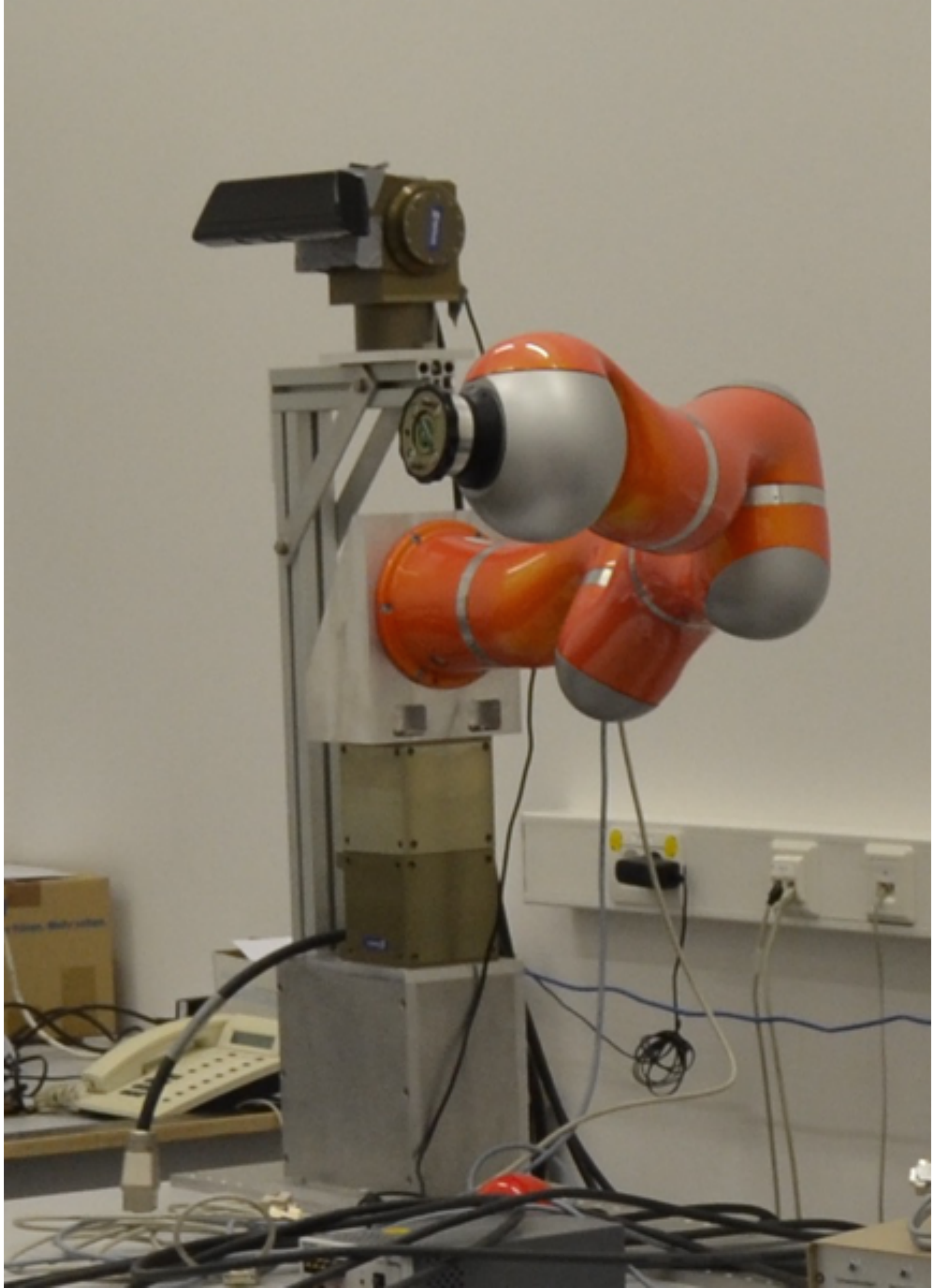


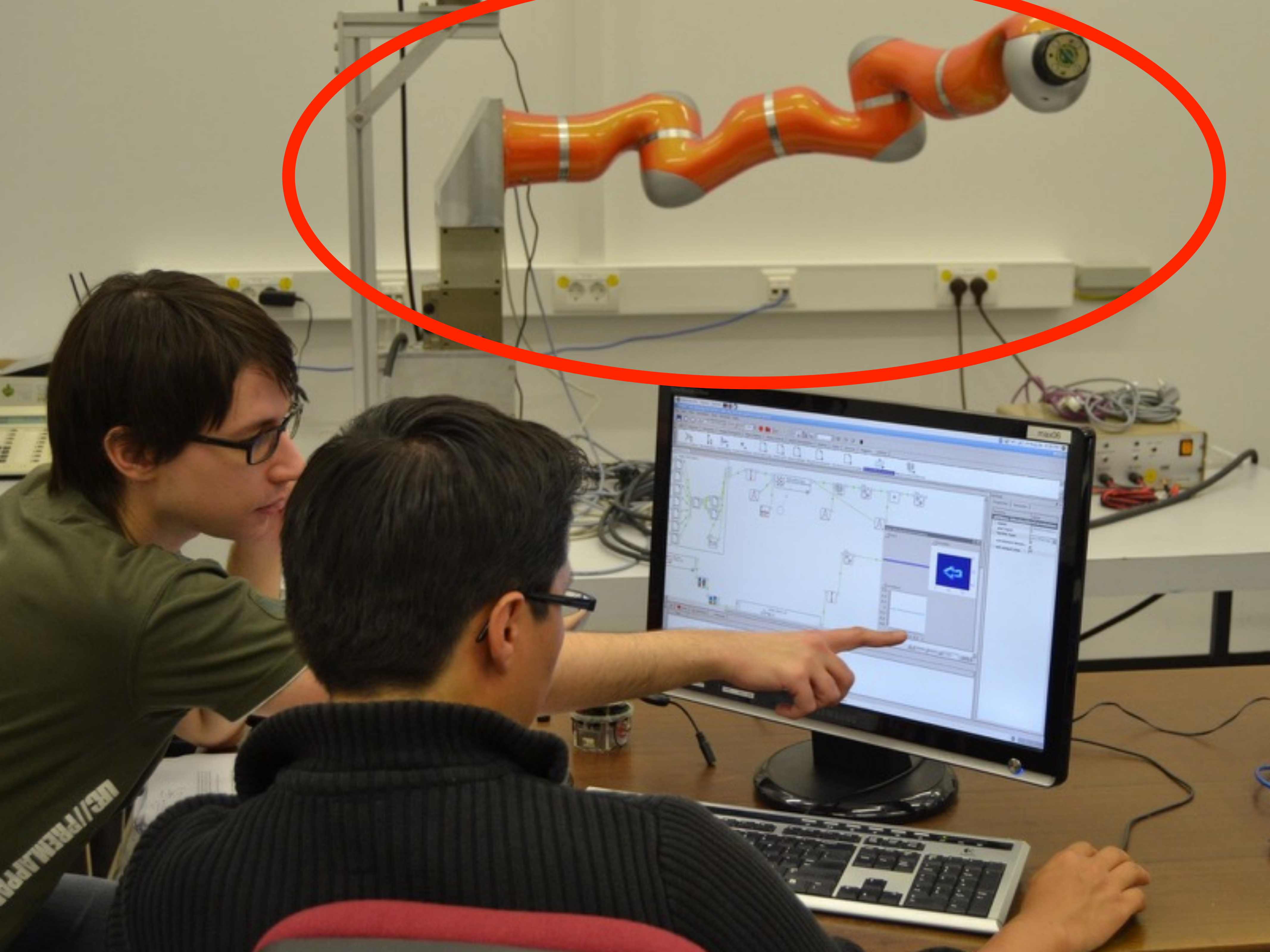
what is perception?

- we do not perceive the stimulus but the world and meaning
- seeing is active:
  - bring objects into the attentional foreground
  - see to answer questions

what is perception?

- attention
- segment
- recognize (invariantly)
- estimate (pose)



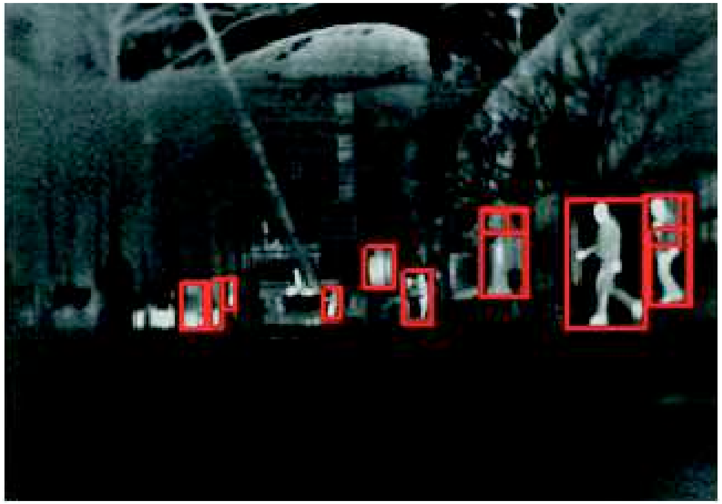


robot vision

- or computer vision or "artificial perception"
- … image/movie understanding rather than image processing
- perception is currently the key bottleneck of autonomous robotics

computer vision entails

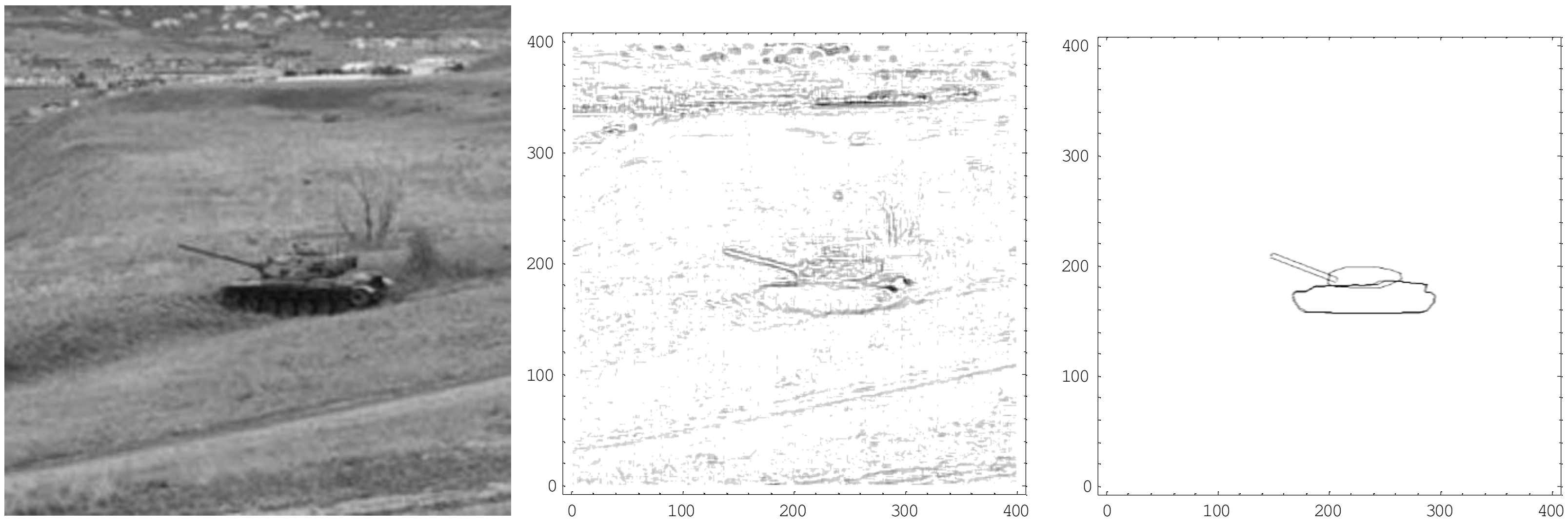
- detection



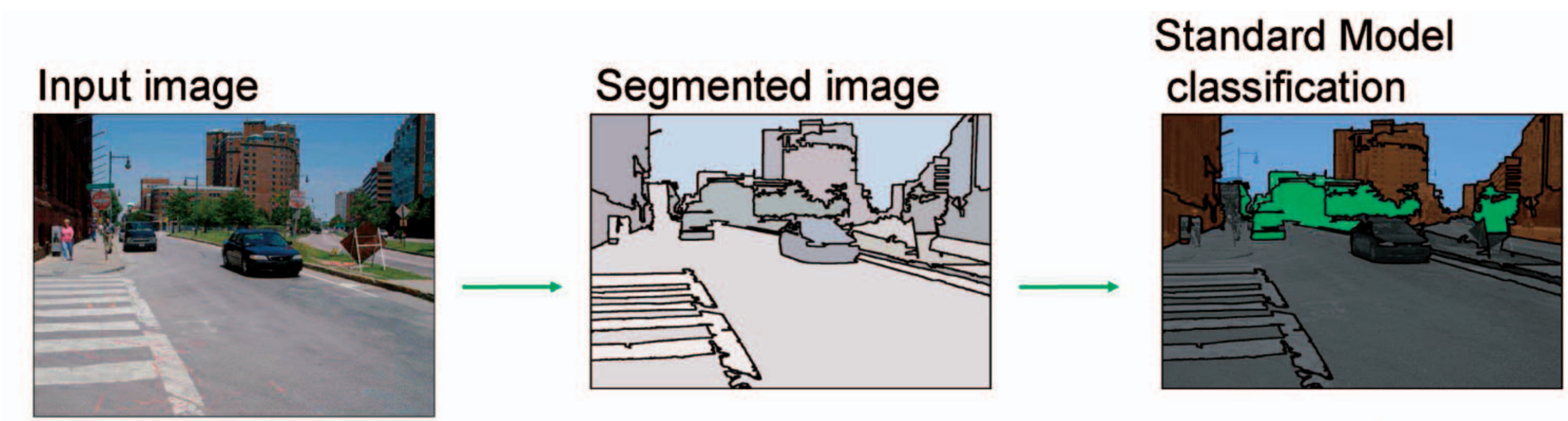
computer vision entails

- segmentation

[segmentation based on template, Arathorn, 2006]

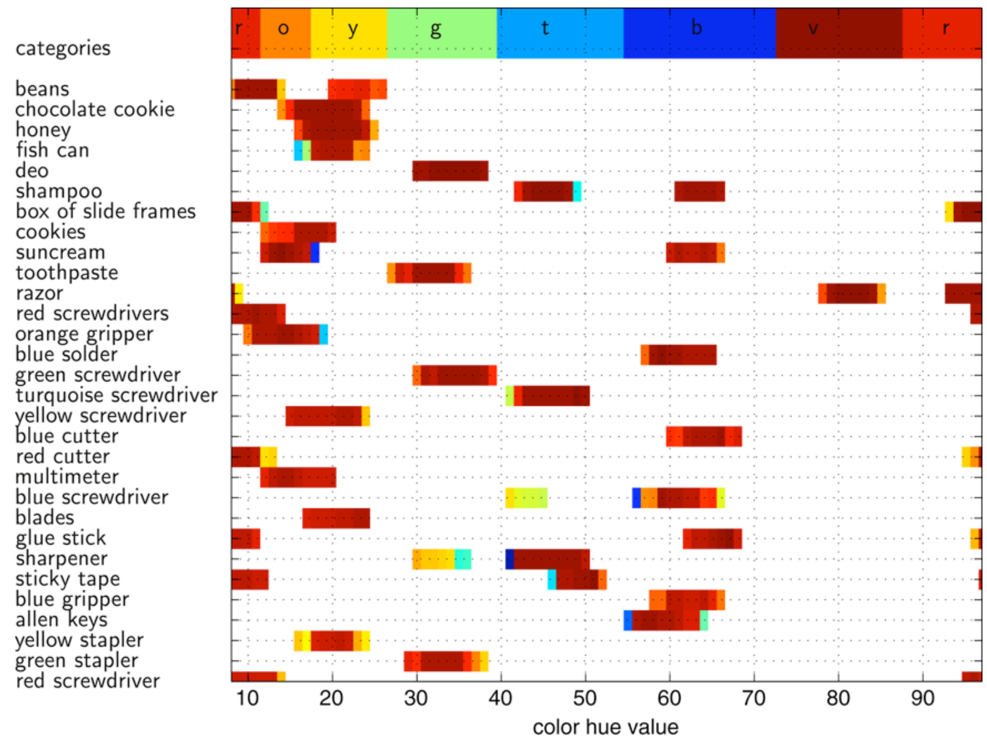


[segmentation based on pixel-wise classification, Serre et al., 2007]



computer vision entails

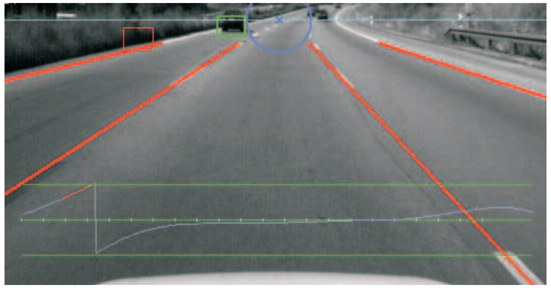
- classification, recognition



[based on low-level features, Faubel, Schöner, 2008]

approach: simply the environment

- environment designed and completely known: industrial robots
  - but also true for many robot demonstrations.. e.g., catching a object that is tracked by conventional technology
- environment designed to simplify task
  - e.g., dishwasher trivializes perception required to achive task
- environment is inherently simply …
  - e.g., roads for autonomous driving



research

- a lot of individual, specific solutions based on insight….
- unsegmented vision for vehicles (everything close is an obstacle)
- learning from examples: machine learning
- exploit analogy to human nervous system…
  - attention
  - feature maps
  - …

(2) interaction with humans

- in part a problem of perception as well…
- meaning is particularly important..
  - e.g., “the red cup to the left of the green cup“ requires generating hypotheses and testing them

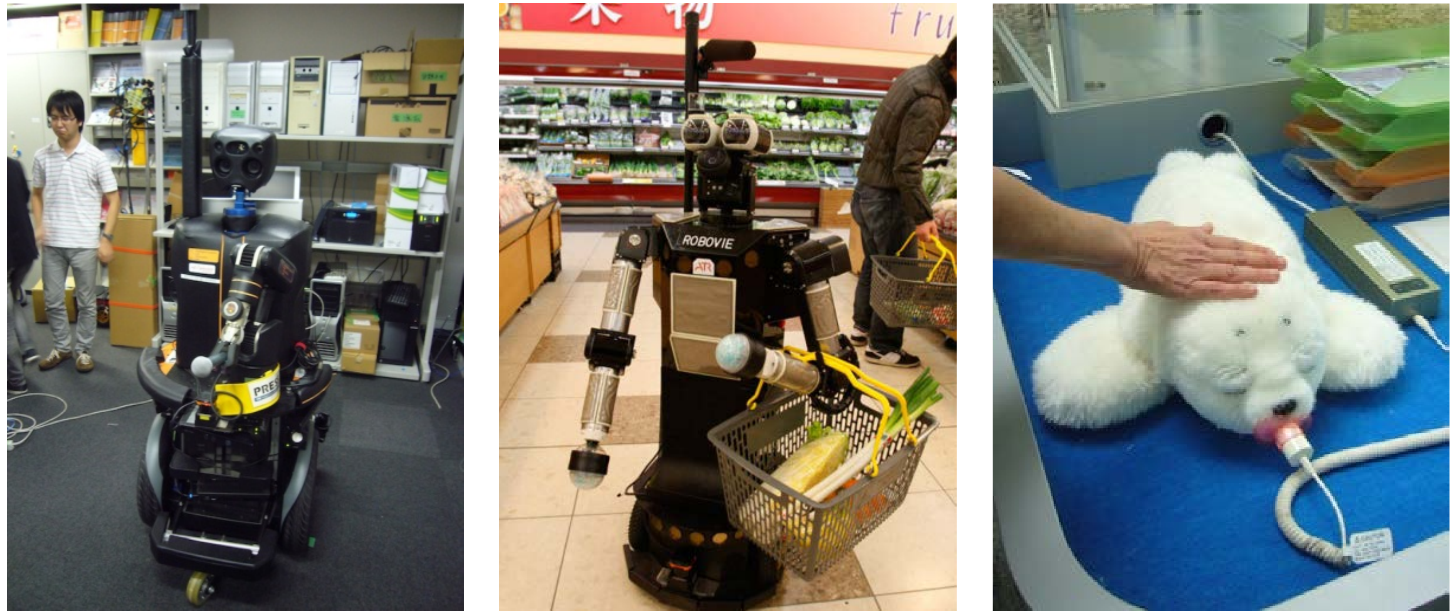


Figure 5.1 From left to right, journalist robot, shopping assistant robot, and the Paro seal robot (courtesy of University of Tokyo, ISI Lab., ATR-IRC Lab., and AIST, respectively).

Figure C.61. Rackham museum guide.

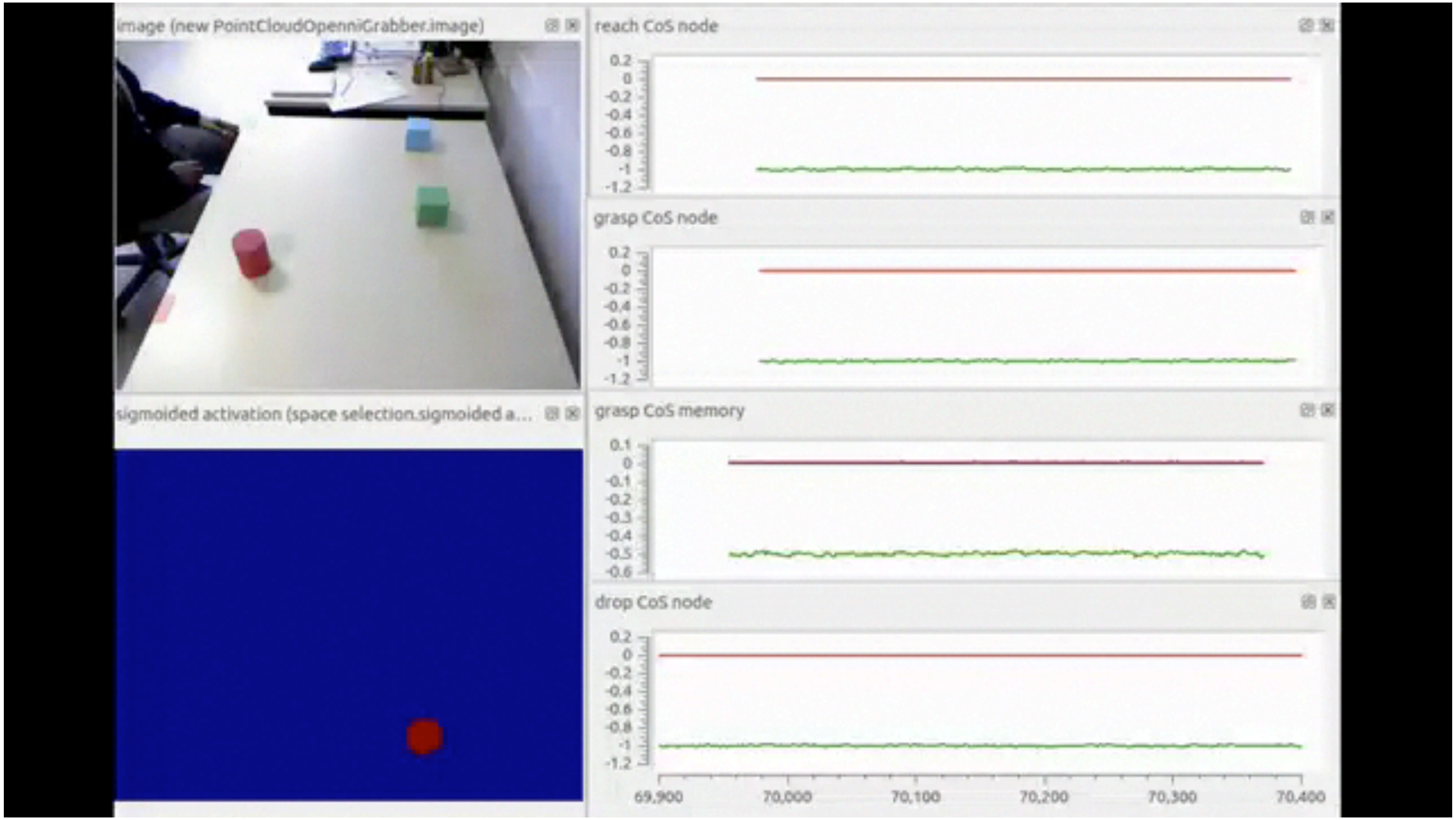
Robovie II, a shopping assistant robot (courtesy of ATR-IRC Lab.).

Figure 5.3 From left to right, manipulators in Robotic Room 1 and Robotic Room 3, and a wheelchair (courtesy of University of Tokyo, Intelligent Cooperative Systems Lab. and AIST [wheelchair]).

research

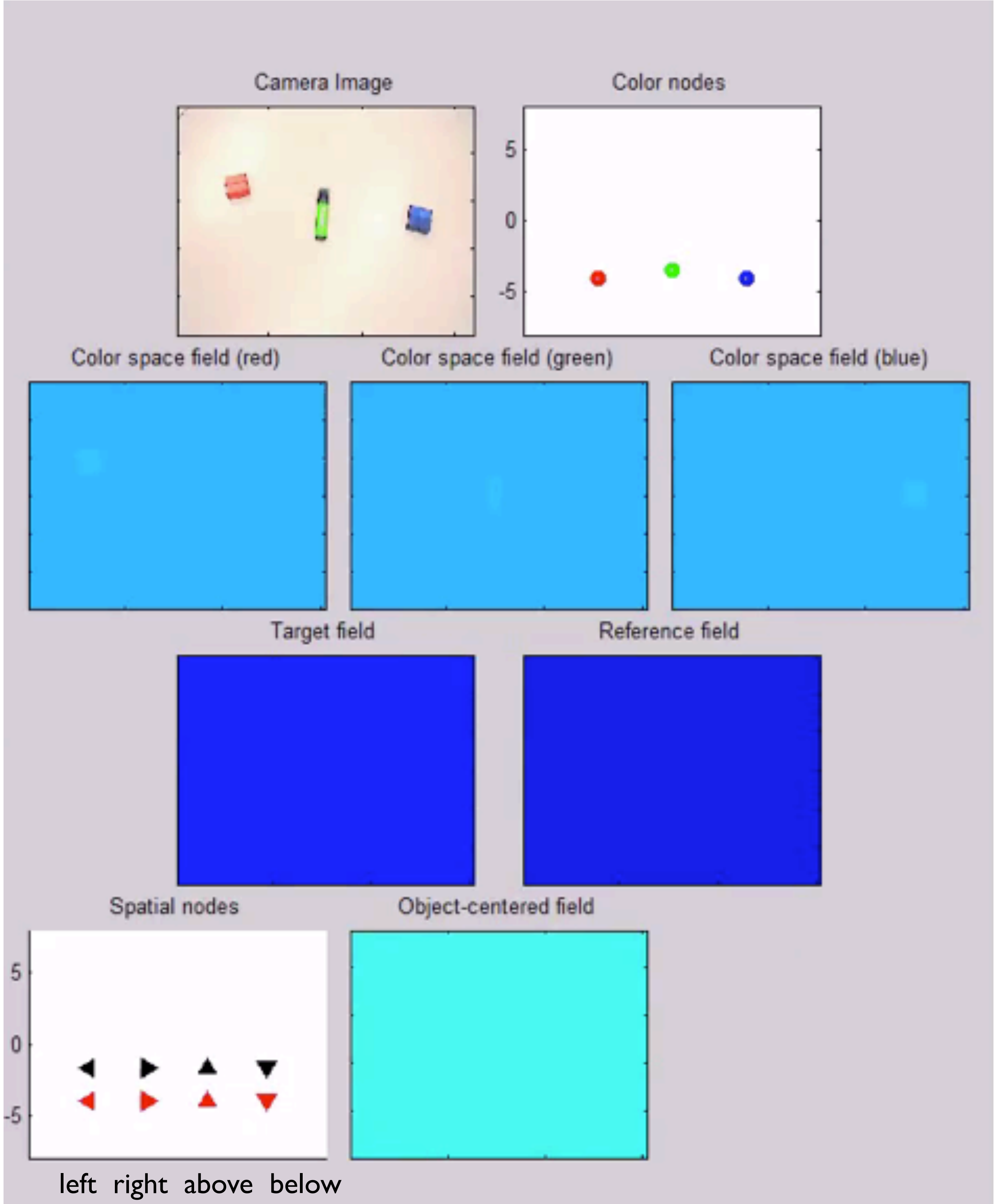
- perceptually grounding language
- intention perception
- gesture recognition
- joint attention
- dialogue management
- emotion recognition

example: action parsing



example: spatial language

- “where is the green object”?



… other applications

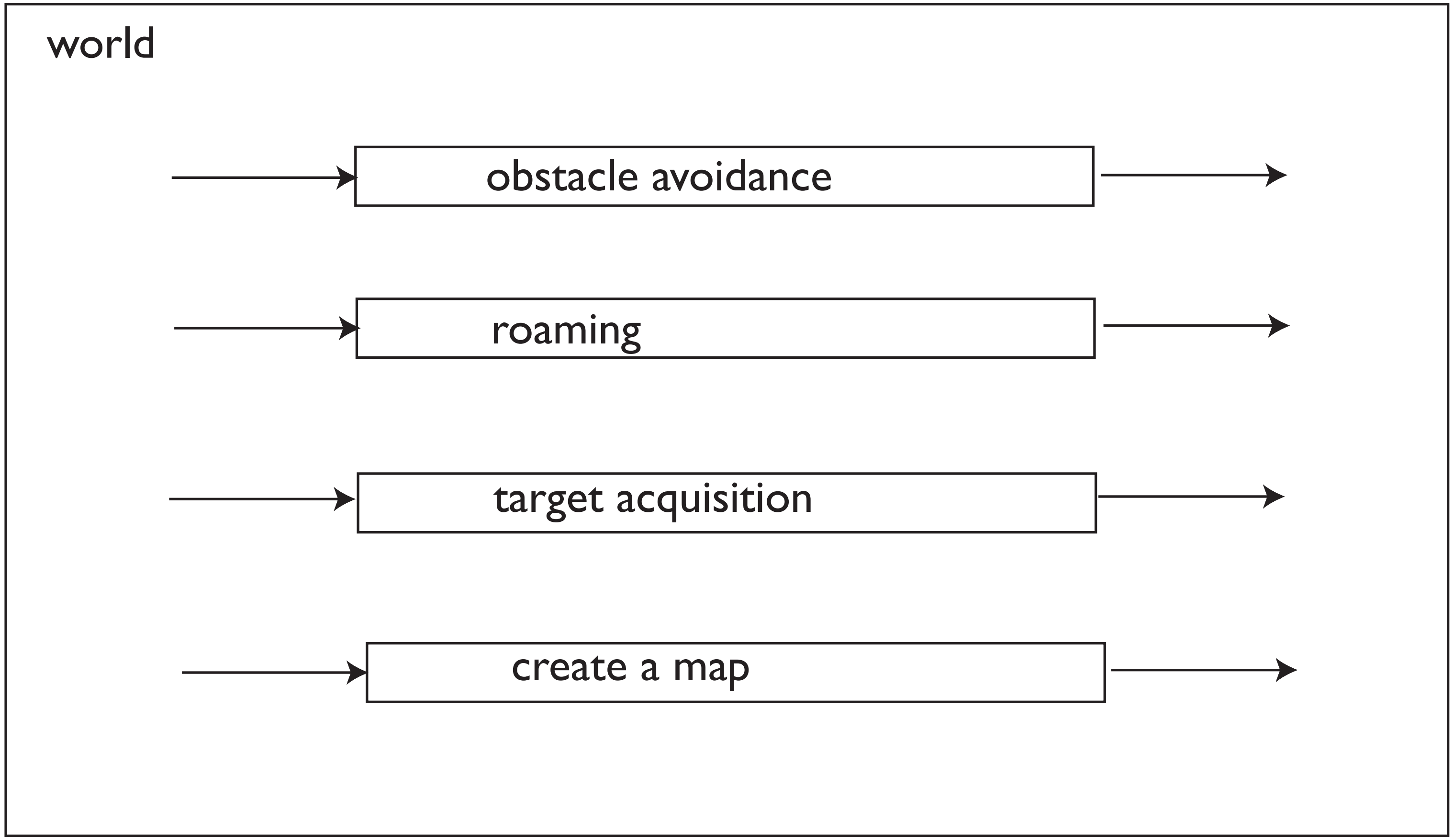
- if successful opens up other applications
  - e.g., disembodied internet based assistant systems (like SIRI) that would share the visual environment of the user (through a phone camera or web cam)

(3) back-ground knowledge

- implicit knowledge how the world works
  - how to open a door
  - that milk is in the fridge
  - how to grasp a glas vs. a cup vs. a spoon
  - how to grasp an object to achieve a particular goal
  - to clear space before moving something to a new place…
- John Searle call this “background” (knowledge, skills)

- “background” is where the traditional approach to artificial intelligence was positioned
  - knowledge bases
  - reasoning
  - action planning
  - architectures

- behavior based robotics
- behavioral organization



research

- special solutions designed/programmed “by hand”
- autonomous learning from experience… largely unsolved
- analogy with human nervous system whose structure reflects “knowledge” about how the world works…

Organizing and flexibly updating timed actions: An attractor dynamics approach

Farid Oubbati, Mathis Richter and Gregor Schöner

Institut für Neuroinformatik
Ruhr-Universität Bochum, Germany

(4) movement generation

- classical approach works very well: control and optimal control
  - => fast, precise trajectory formation in industrial robots
- but:
  - high demands on perception
  - less well developed for online updating in dynamic scenes
  - soft actuation for safe interaction with humans

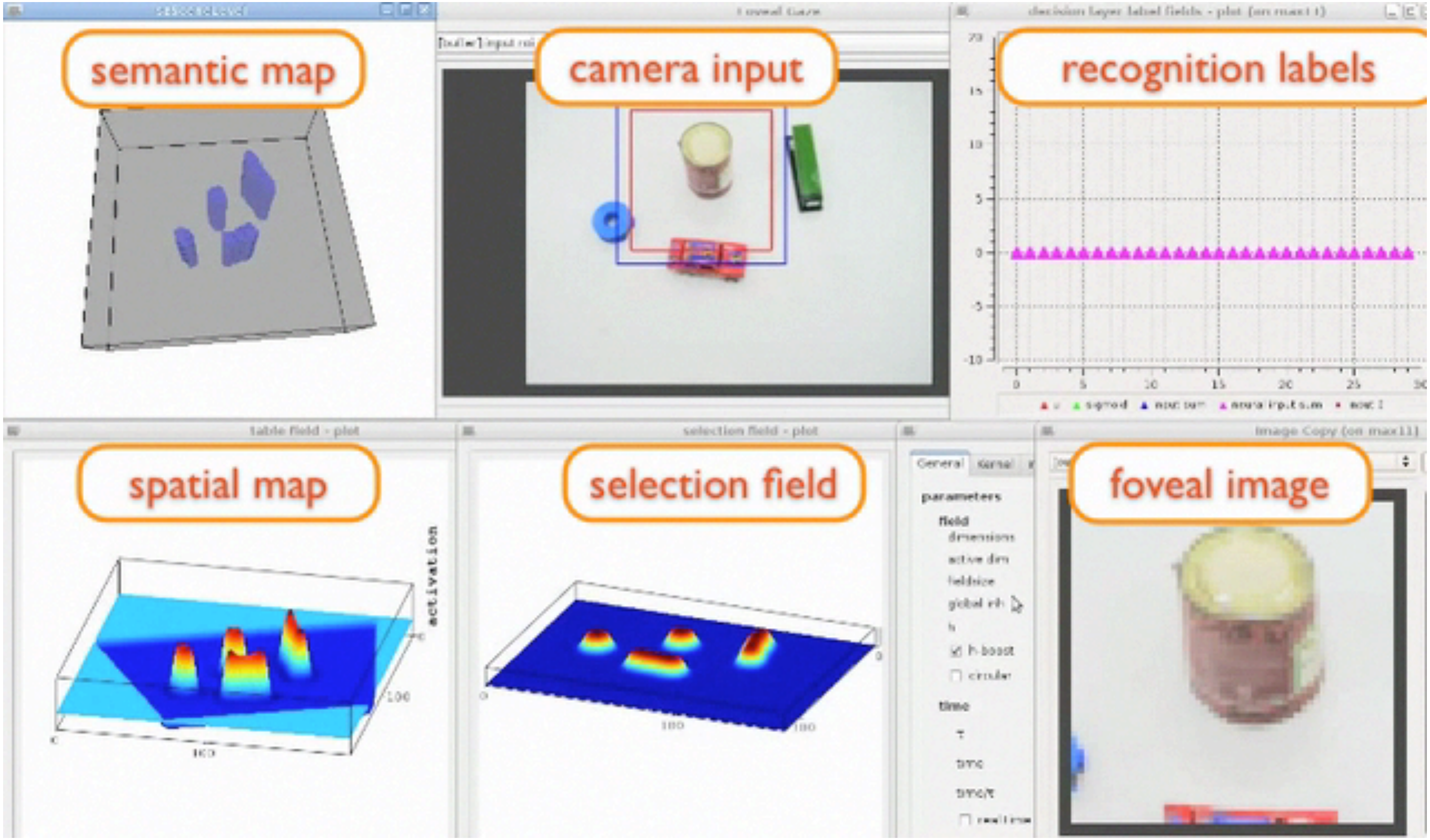
research

- exploit analogies with human movement coordination, movement primitives
- exploit analogy with muscle: soft visco-elastic actuators

Neural computation: learning from analogies with the human nervous system

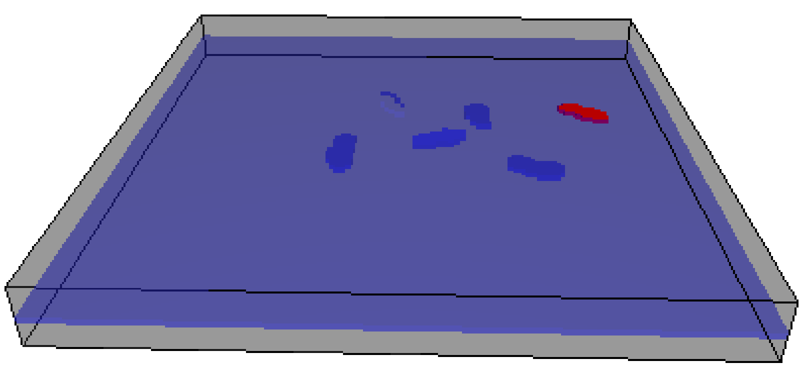
(I) visuel cognition

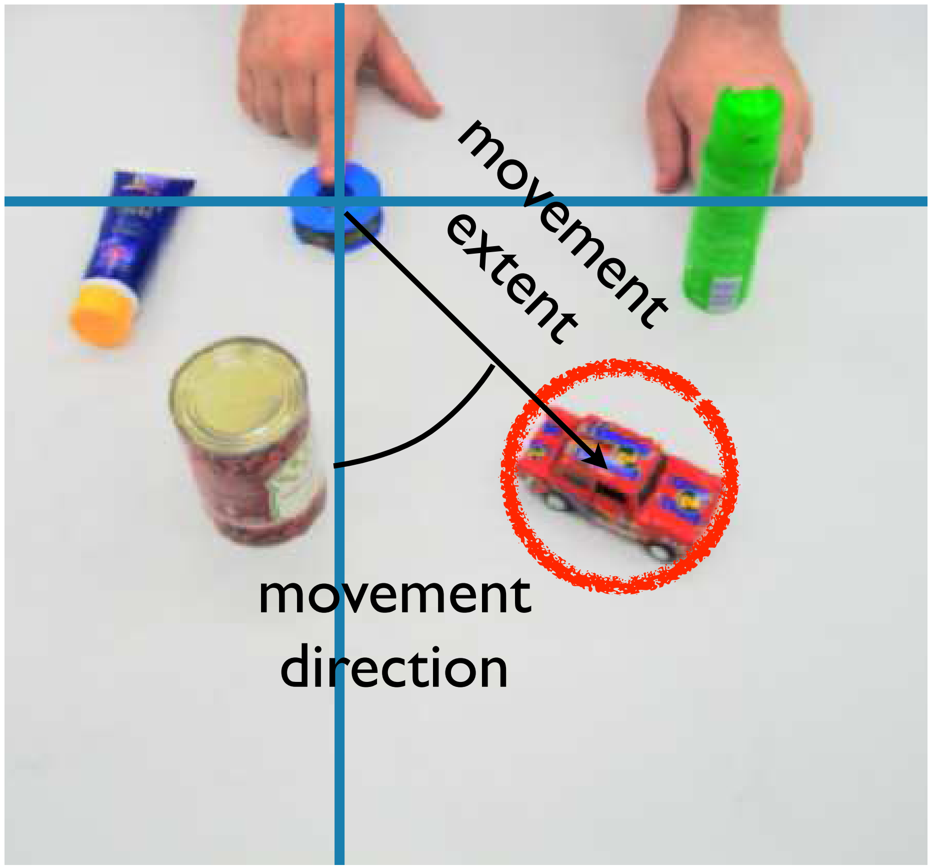
- feature maps, within neural activation controls the attentional foreground
- and that are continuously linked to sensory input …
- sequences of attentional selection decisions generate scene representations


semantic map
camera input
recognition labels
spatial map
selection field
foveal image

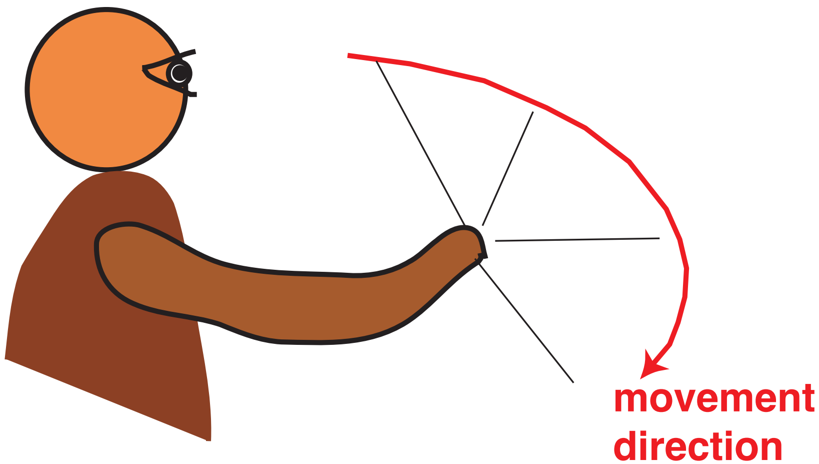
(2) movement planning

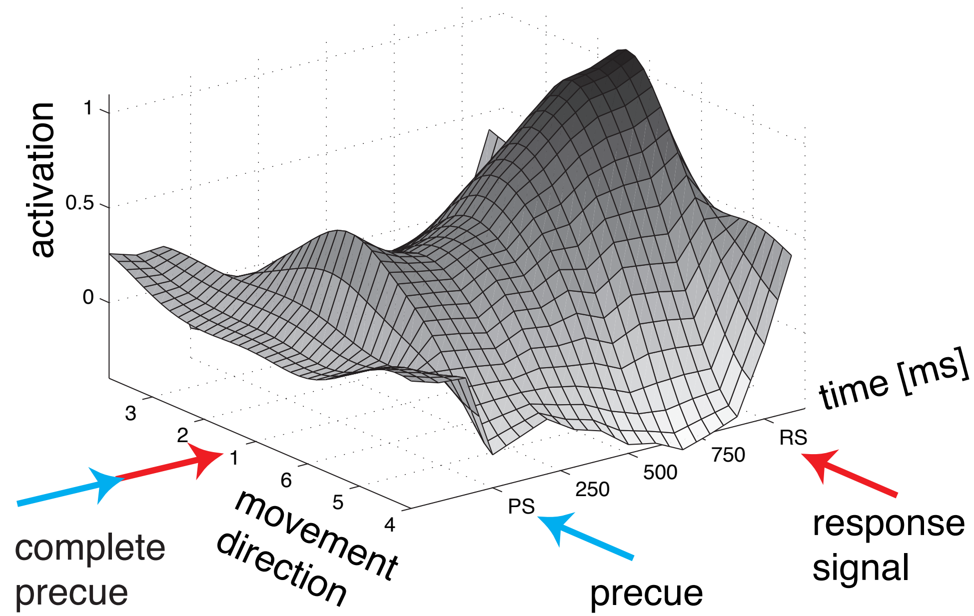
- is driven by scene representation

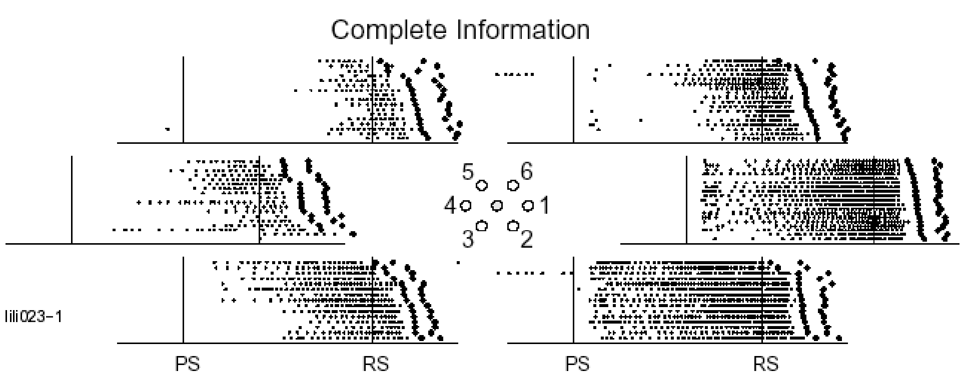


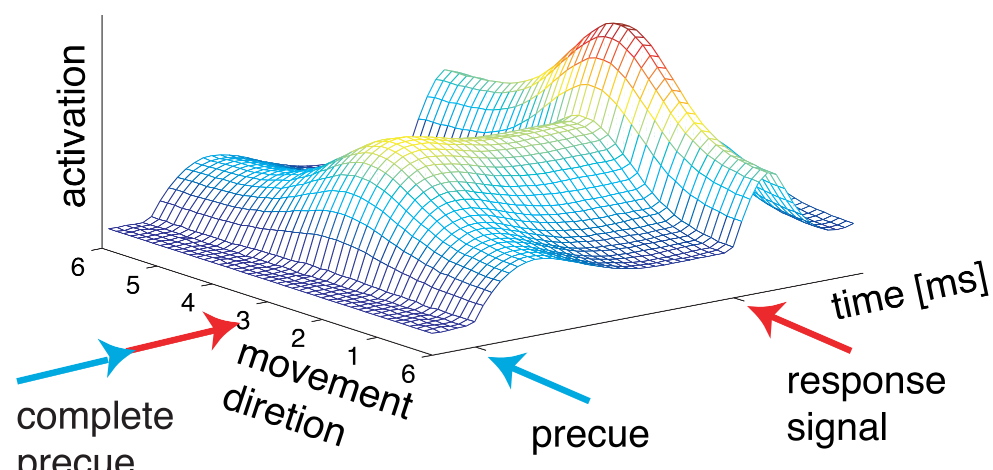


… based on neural activation fields



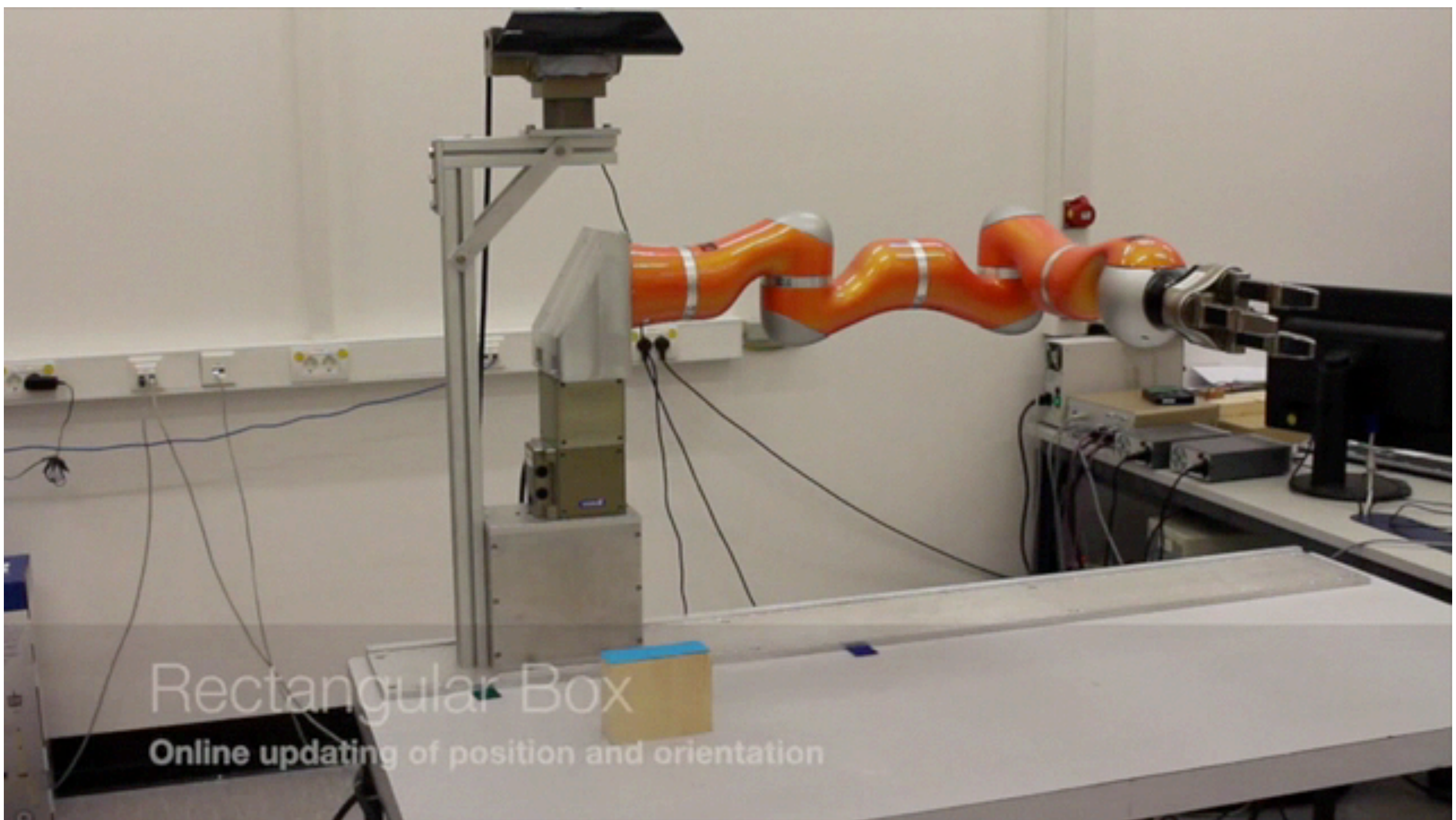






Bastian, Riehle, Schöner, European Journal of Neuroscience, Vol. 18, 2047-2058 (2003)

… online updating

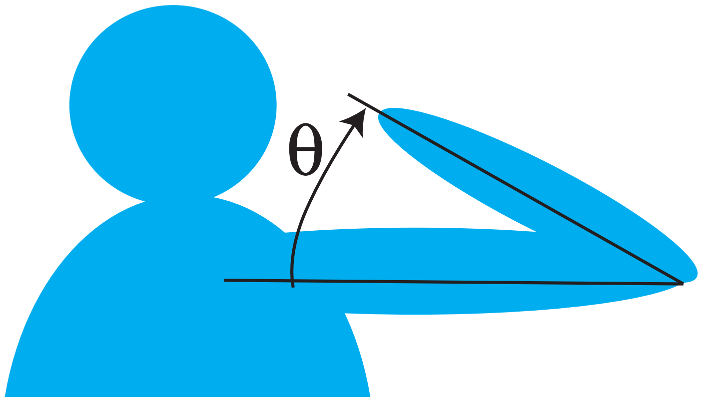


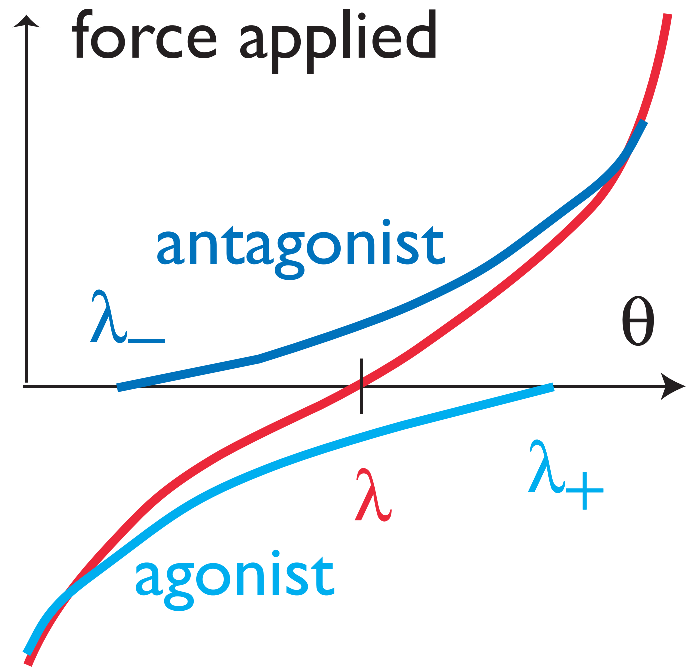
(3) timing and coordination

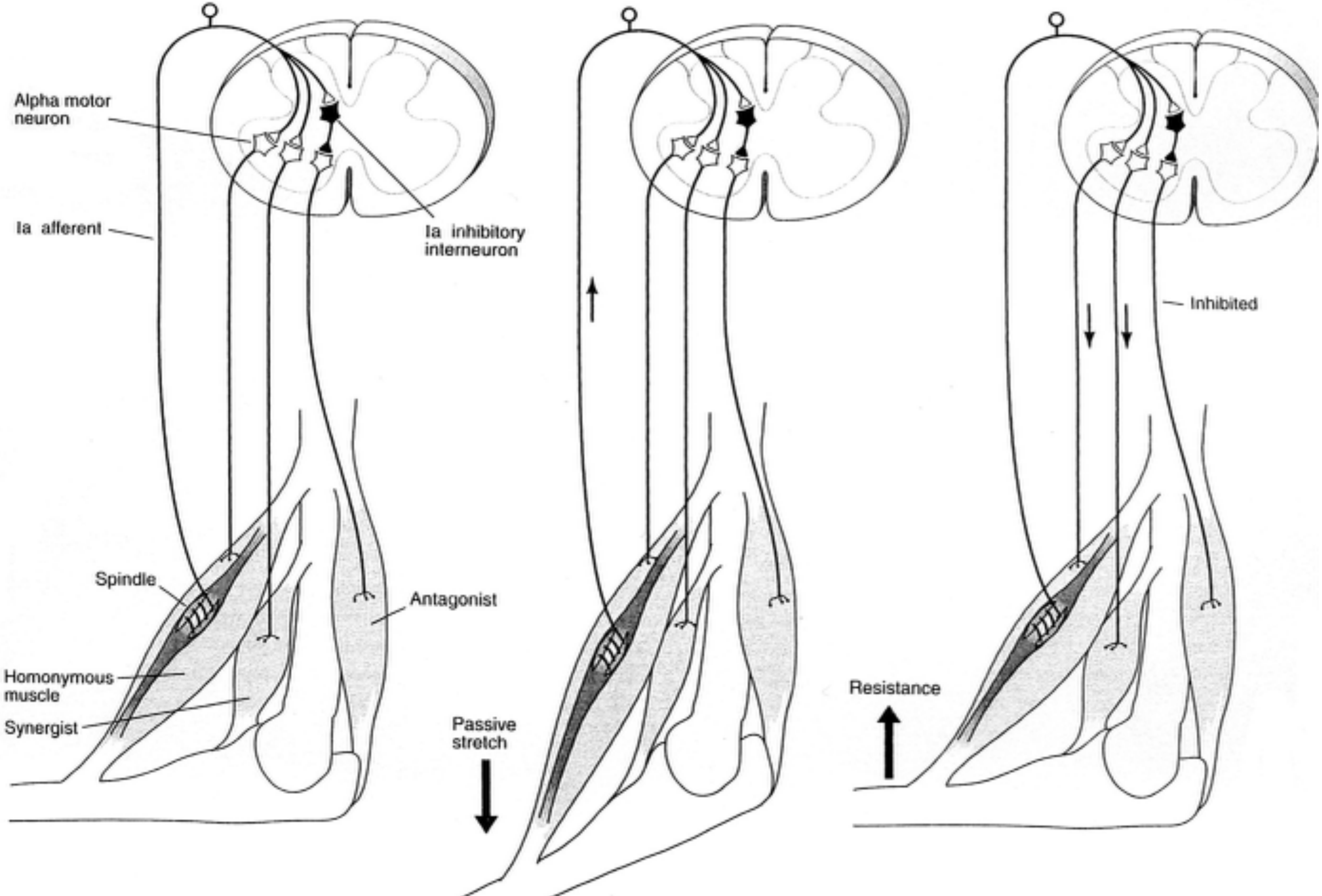
- all movement is coordinated, timed, and multi-sensory…

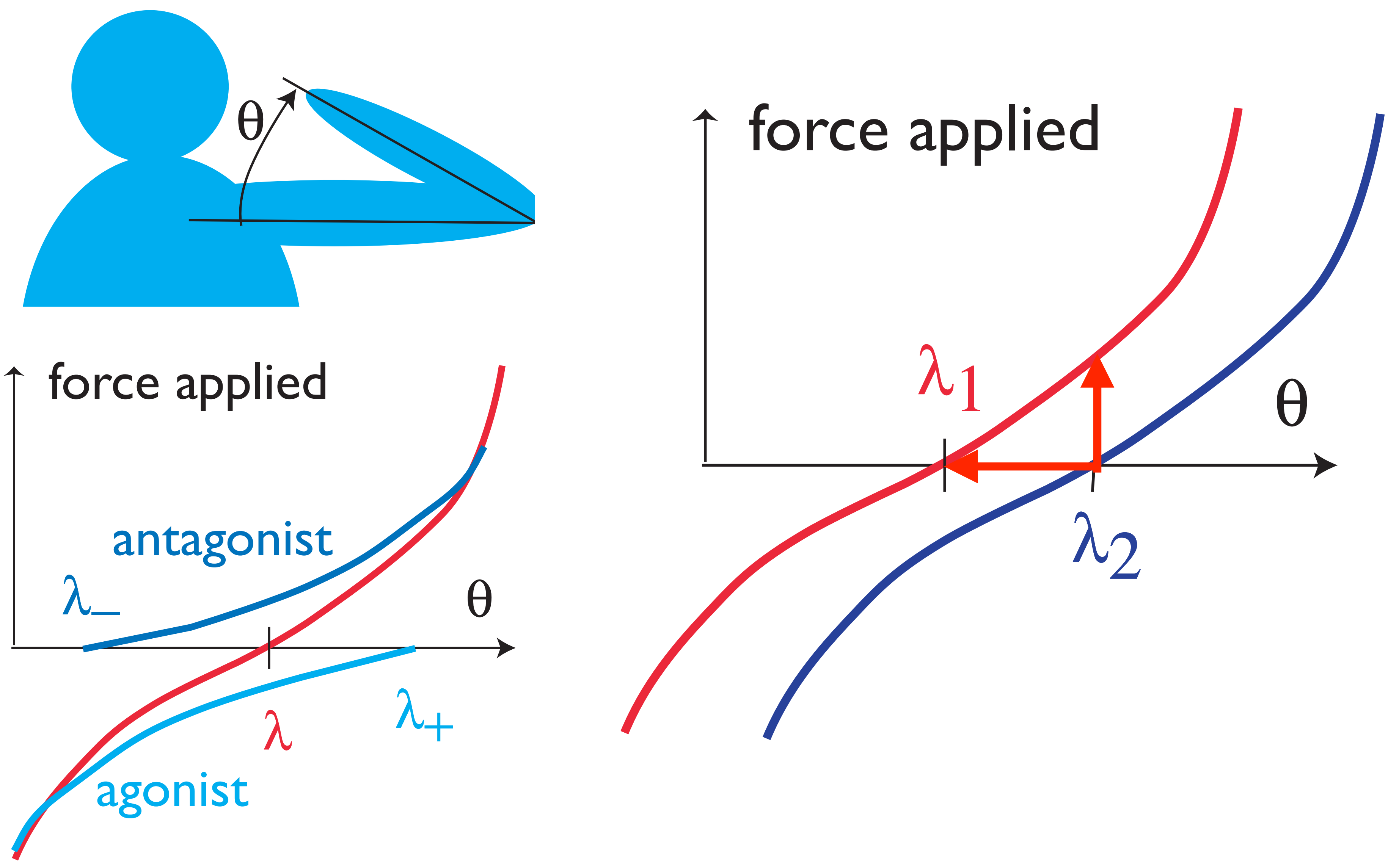
(4) muscles

- are tunable (dampened) springs

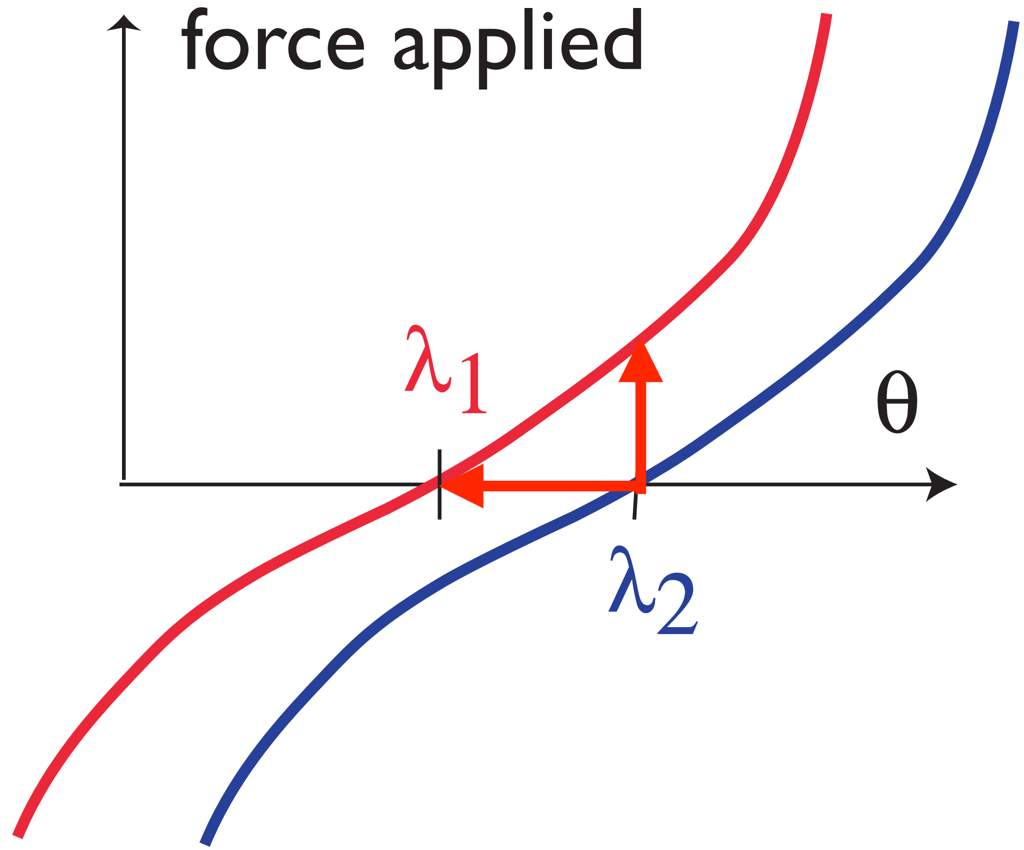





Alpha motor neuron
Ia afferent
Ia inhibitory interneuron
Spindle
Antagonist
Homonymous muscle
Synergist
Passive stretch
Resistance
Inhibited

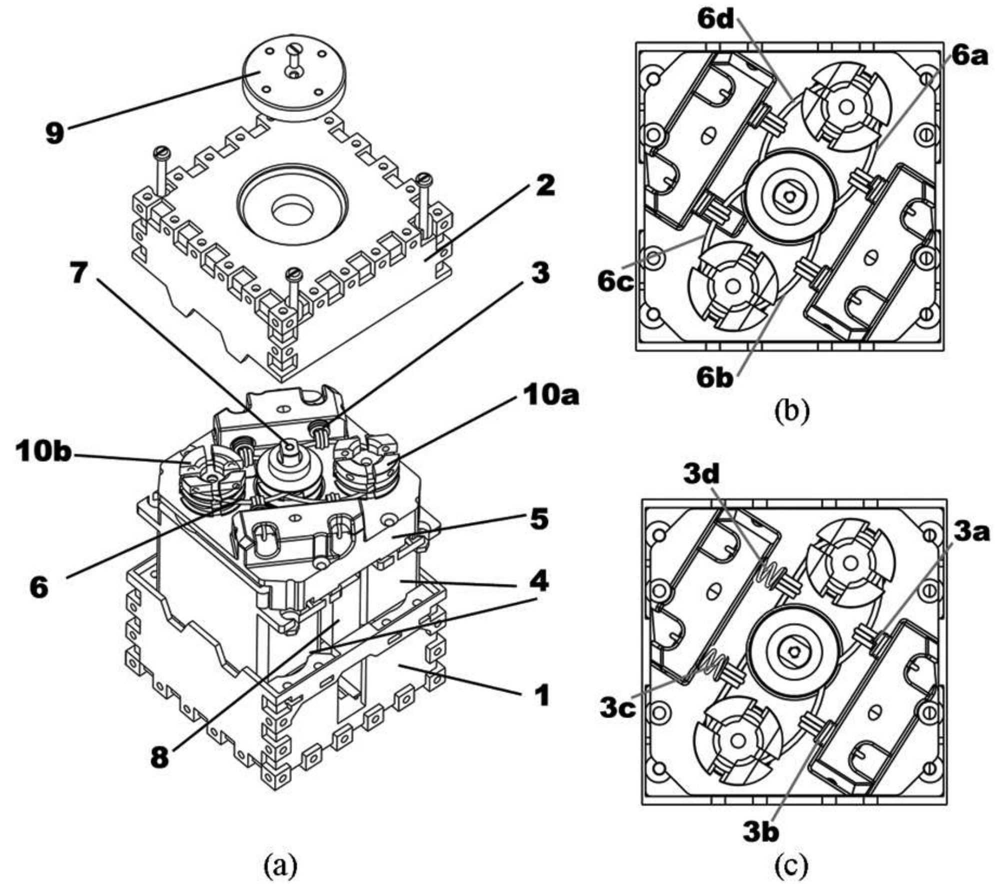

θ
force applied
antagonist
λ_
θ
λ
λ+
agonist
force applied
λ1
θ
λ2

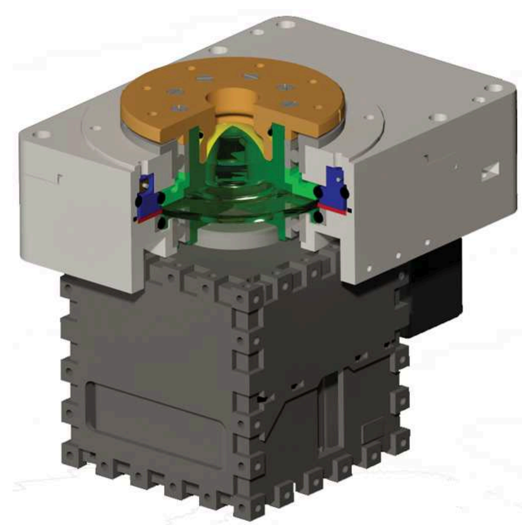
- muscle activation and force result from spatial command

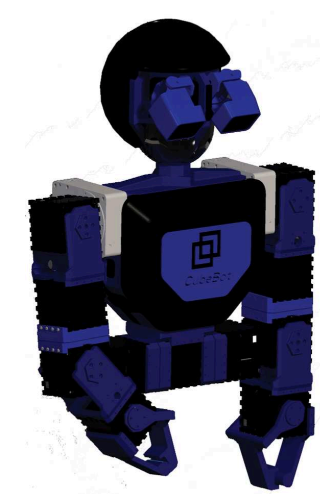


research

- active elastic actuators



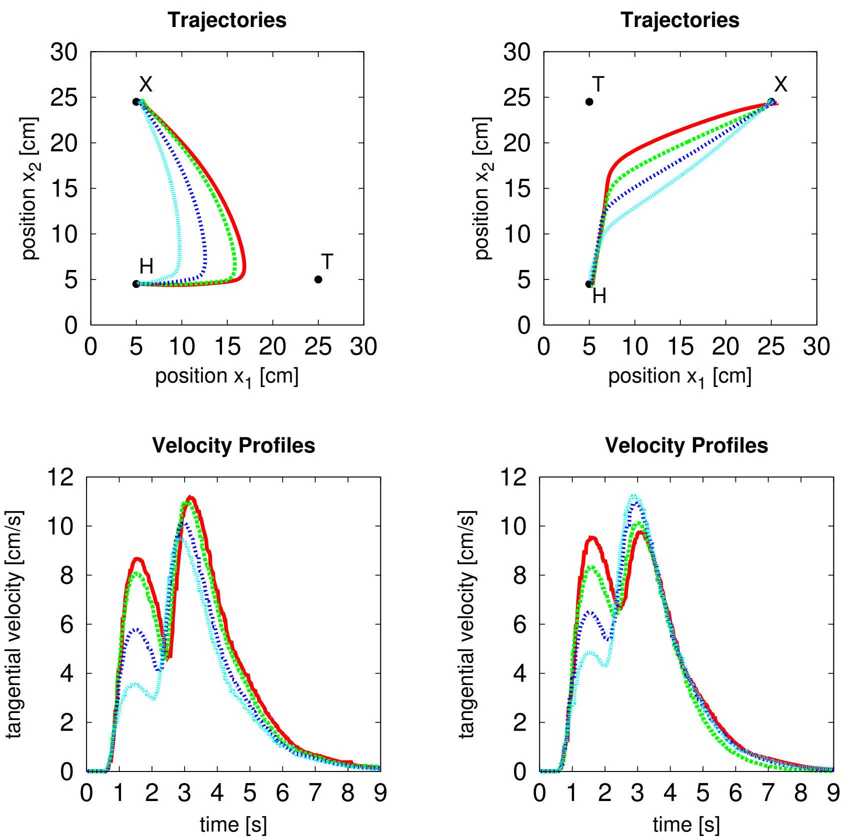




[Antonio Bicchi]

… our own

- online updating in a neural dynamic architecture with simulated muscles…



[Zibner, Tekülve, Schöner, submitted]

Neural computation: learning about human perception/cognition/action

- test theories: do models actually generate behavior?
- insight into problems the CNS must solve
  - e.g., coordinate transforms
- insight into problems the CNS need not solve
  - e.g., optimal control