Movement generation by Humans and Robots: a dynamical systems perspective: Introduction

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Human movement generation

homo habilis or homo faber ...

- we are the skillful species..
- fluent sequences of movement, linked on-line to sensory information
- flexibility: multiple motor skills which can be adapted and be performed concurrently
- excellent fast scene perception
- fine manipulation skills

Human movement generation

- posture/balance
- locomotion
  - navigating: moving through space
  - stepping
- rhythmic (dance, music)
- whole body skills, sports
- reach, grasp, manipulate
- speech articulatory movement

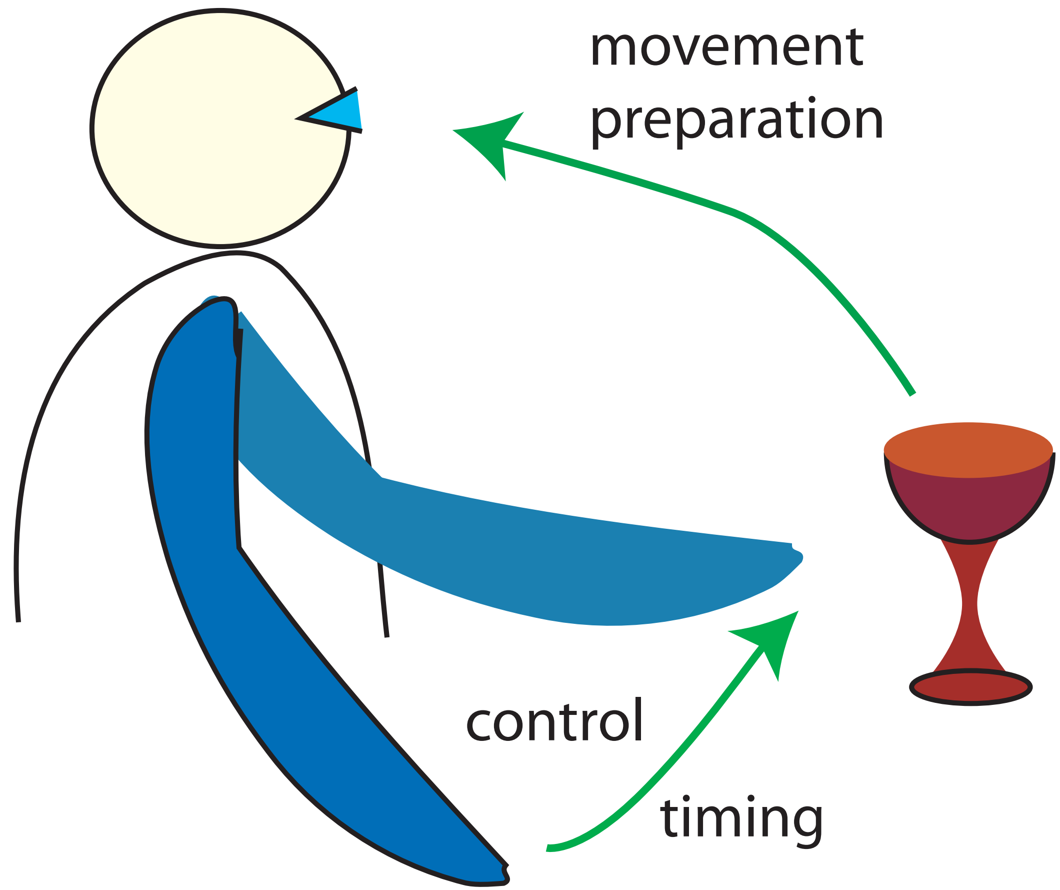
- involuntary... automatic
- voluntary
- object oriented

What is motor control?

- … the neural processes underlying the movement of organisms…
- not just any movement
  - bacteria, plants: tropisms
  - falling from a tower…

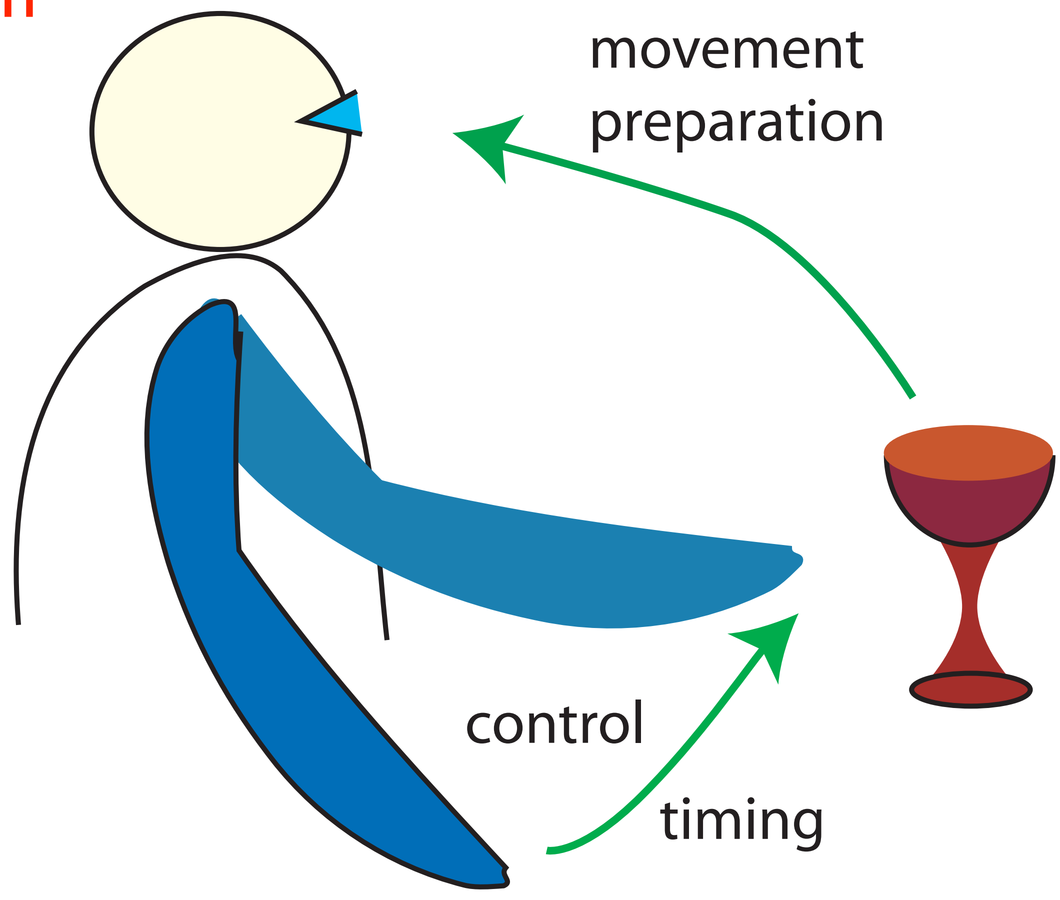
What is entailed in generating an object-oriented movement?

- scene and object perception
- movement preparation
- movement initiation and termination
- movement timing and coordination
- motor control
- degree of freedom problem



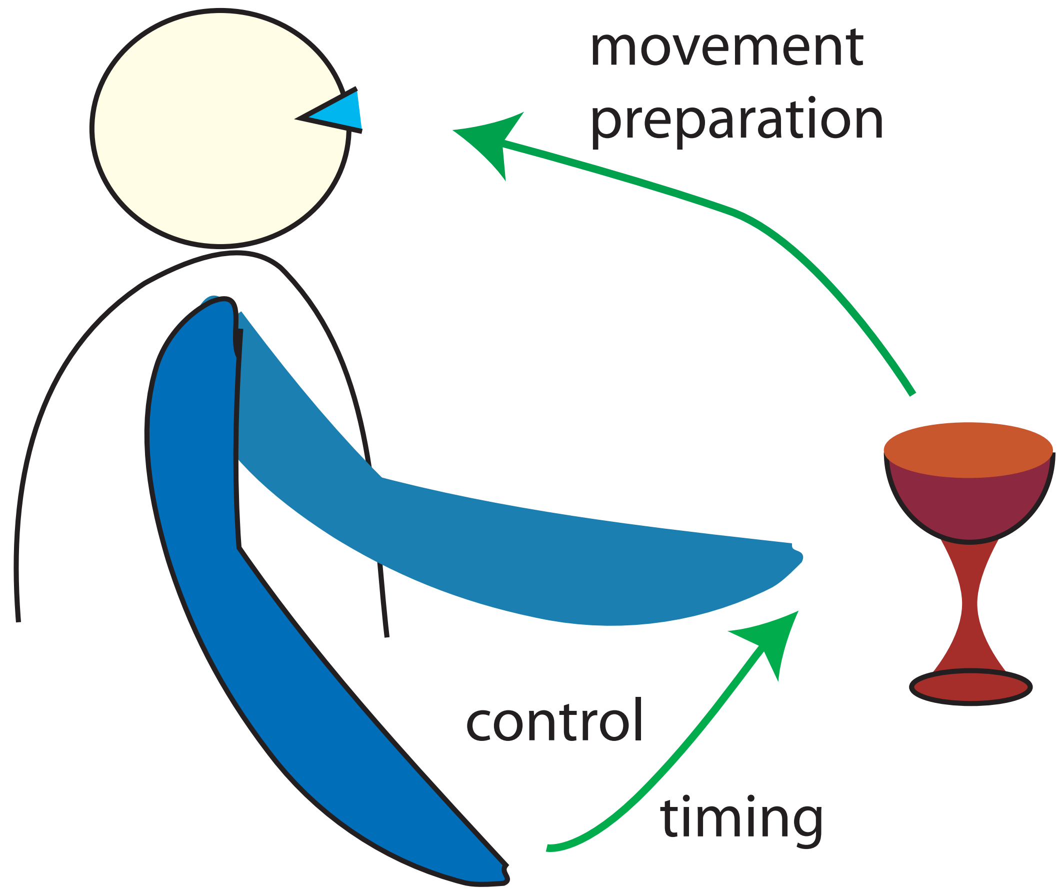
What is entailed in generating an object-oriented movement?

- => spans perception, cognition and control



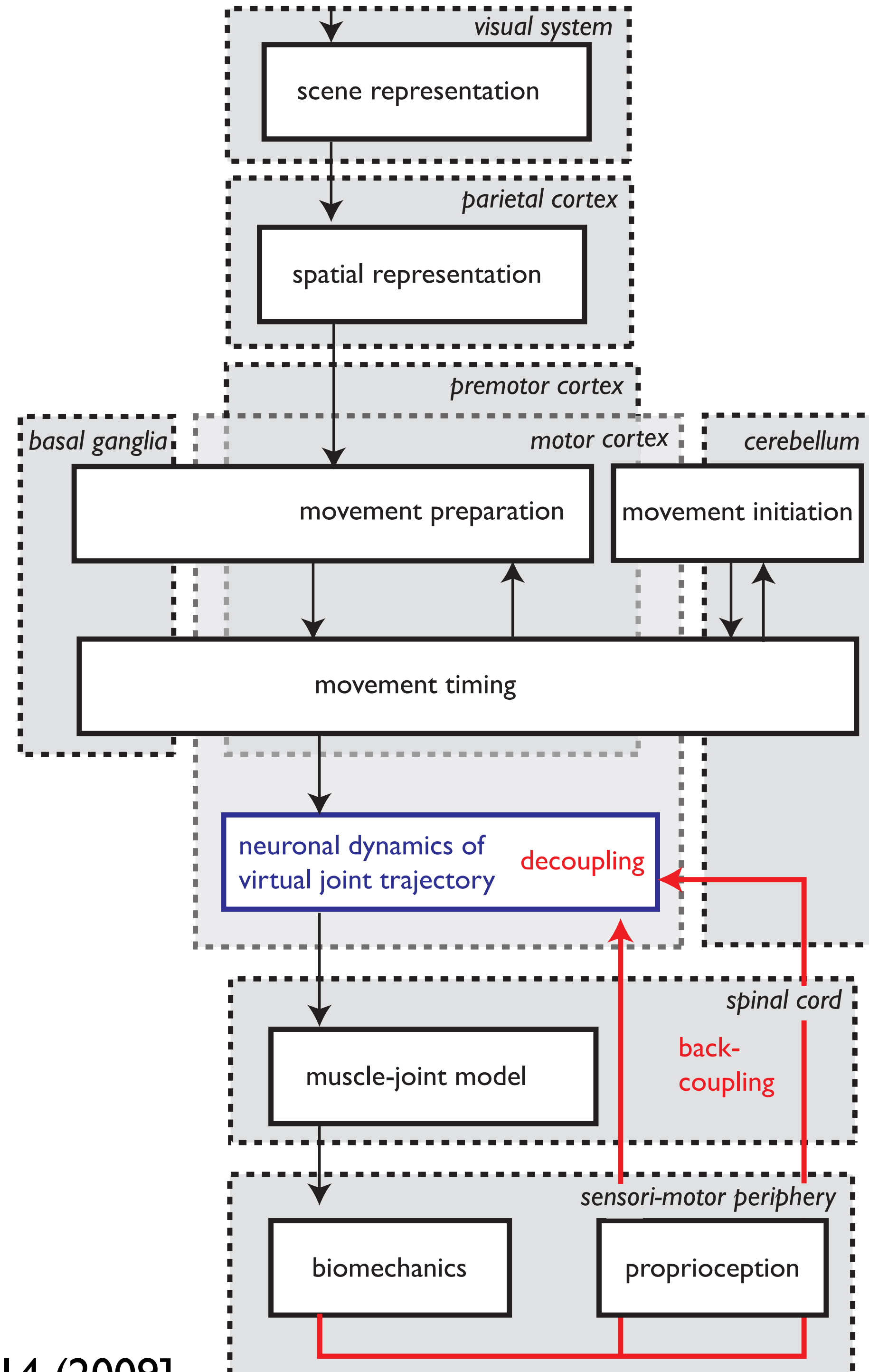
What is entailed in generating an object-oriented movement?

- it is difficult to isolate any individual process
- => this is why movement is so hard to study
- => this is why it is critical to understand integration



in this course I will…

- take you through the component process
- illustrate theoretical concepts relevant to understanding motor behavior
- summarize neurophysiology
- use robotics to illustrate ideas

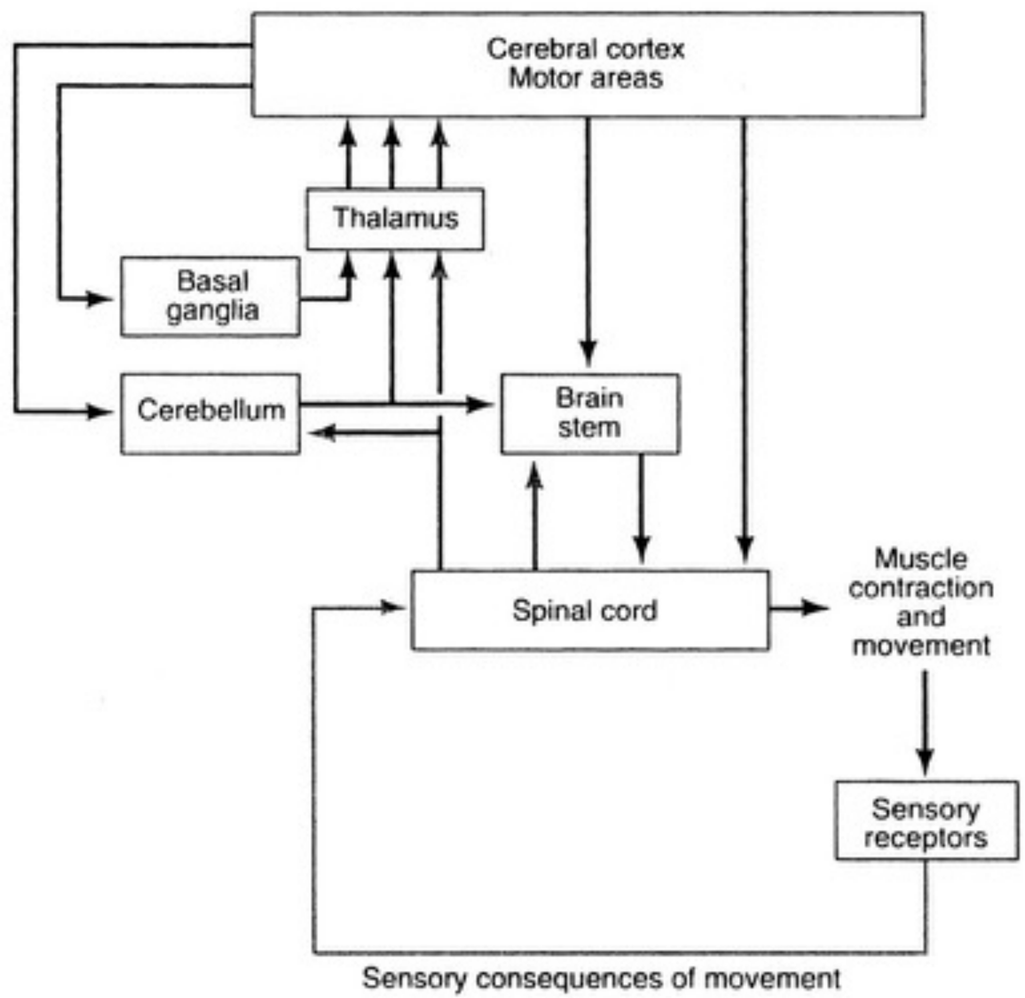


[Martin, Scholz, Schöner. *Neural Computation* 21, 1371–1414 (2009)]

Neurophysiology of movement

three systems

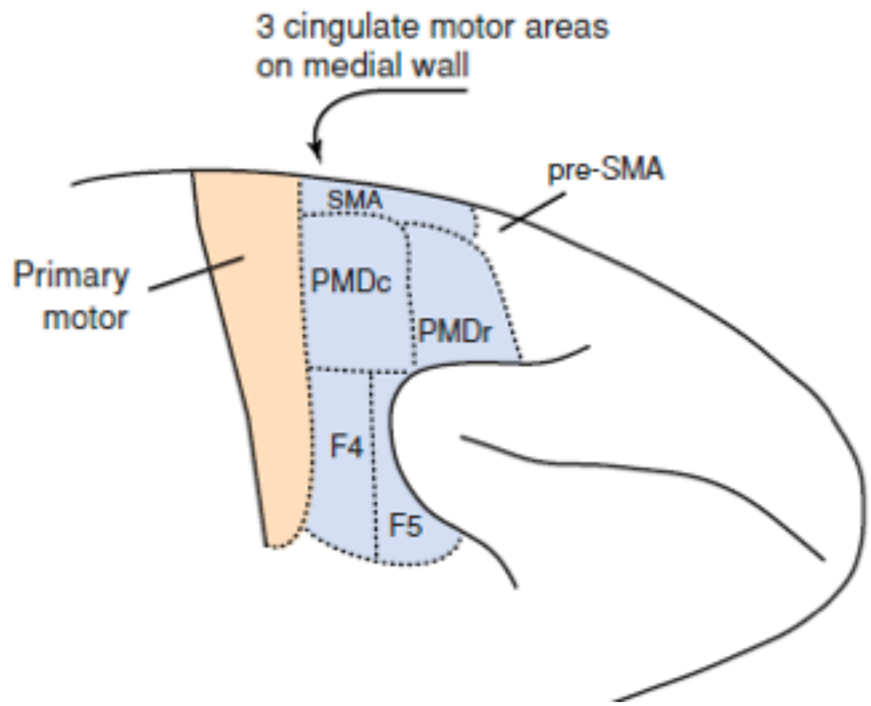
- the levels of movement generation
  - cortex
  - brain stem
  - spinal cord
- 2 modulatory systems
  - loop through basal ganglia anc thalamus
  - loop through cerebellum and thalamus



[Kandel, Schartz, Jessell, Fig. 35-3,
all figures are from the 3rd edition]

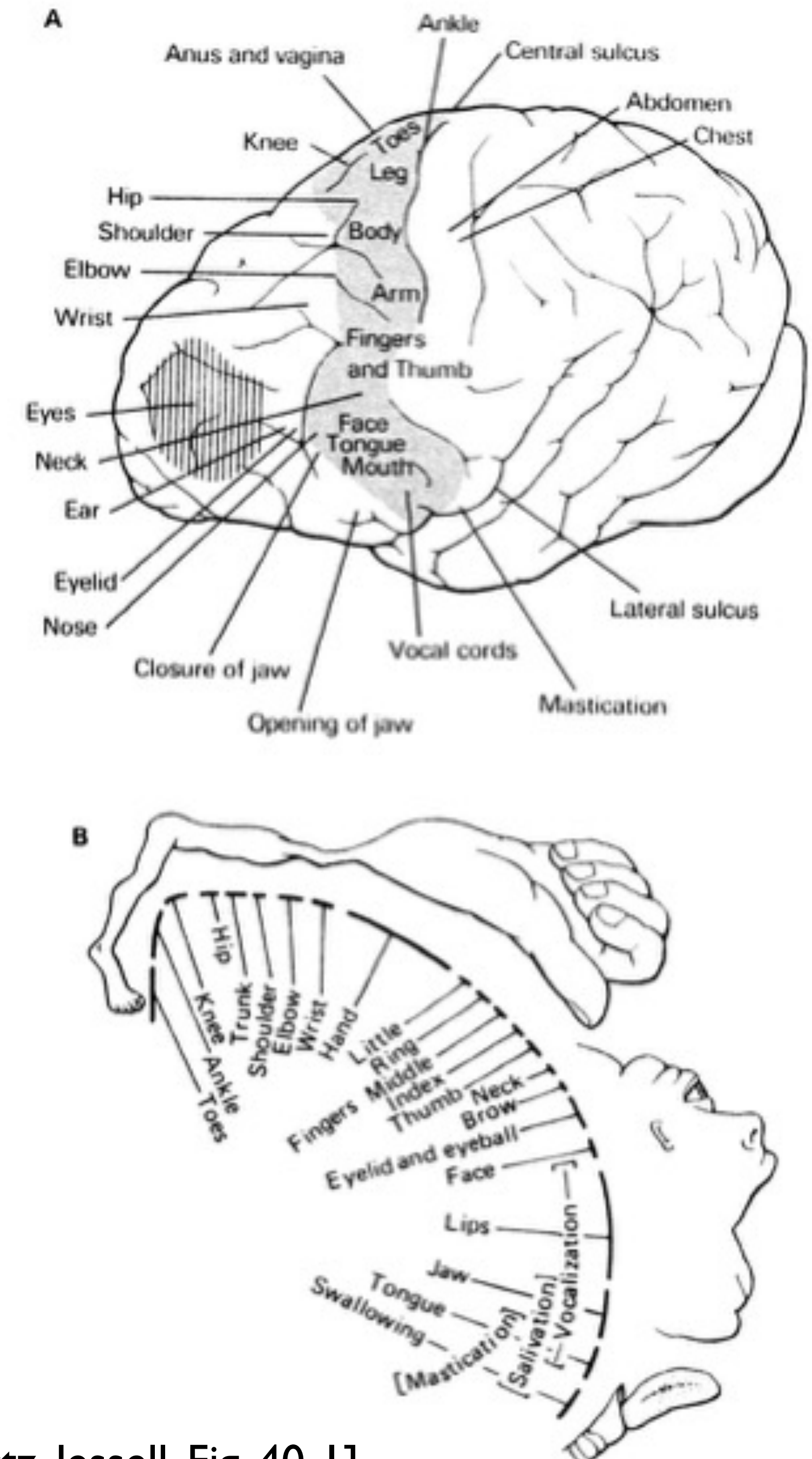
the motor cortex

- provides direct input to muscles through cortico-spinal projects
- and inputs to spinal circuits and to brain stem



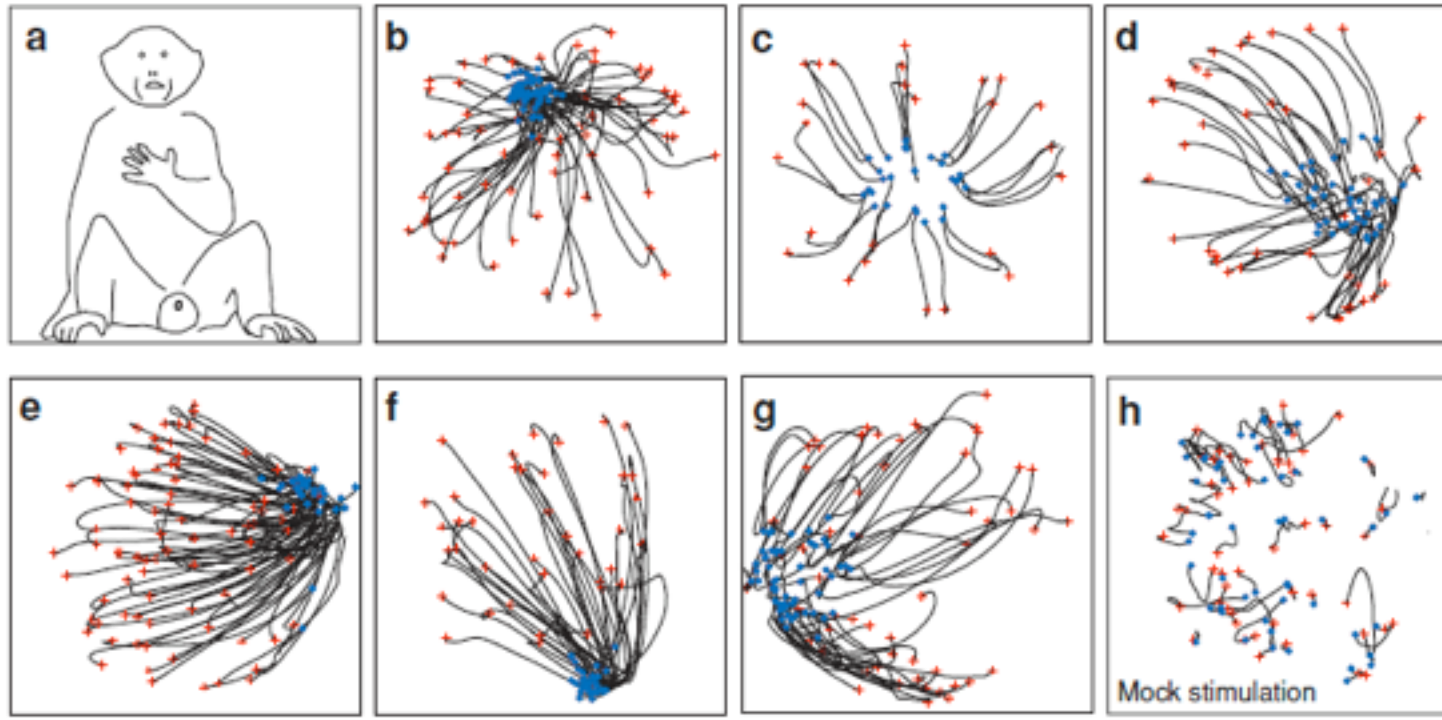
the cortico-spinal projection

- leads to effector activation when motor cortex is excited
- motor homunculus



[Kandel, Schartz, Jessell, Fig. 40-1]

the cortico-spinal projection



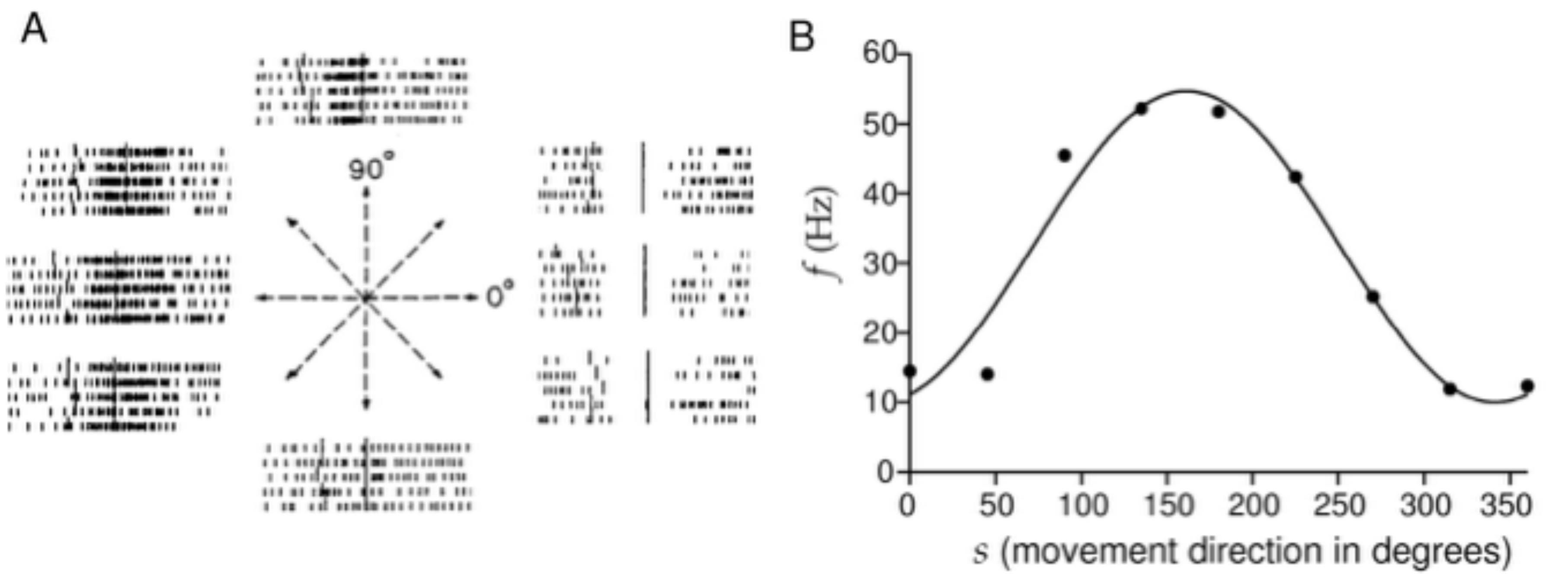
[Graziano, 2006]

- stronger longer-lasting stimulation may lead to activation of complete movements
- (recruiting multiple areas into the loop)

in the motor cortical areas

- movement parameters are encoded
  - e.g. direction of end-effector movement
  - e.g., direction of force-vector
- in the sense of broad tuning

motor cortex: movement direction

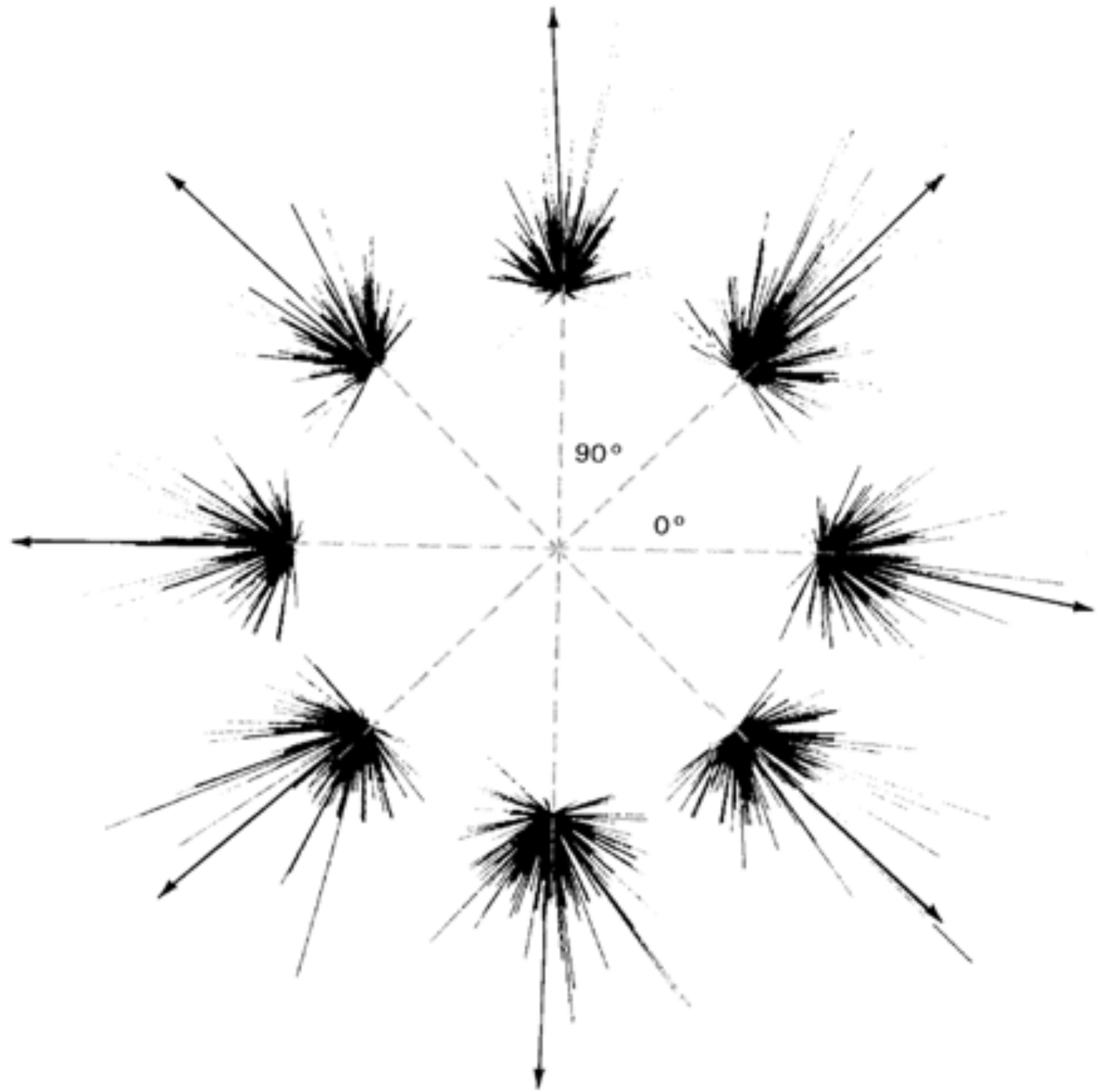


[Georgopoulos, A et al.]

B

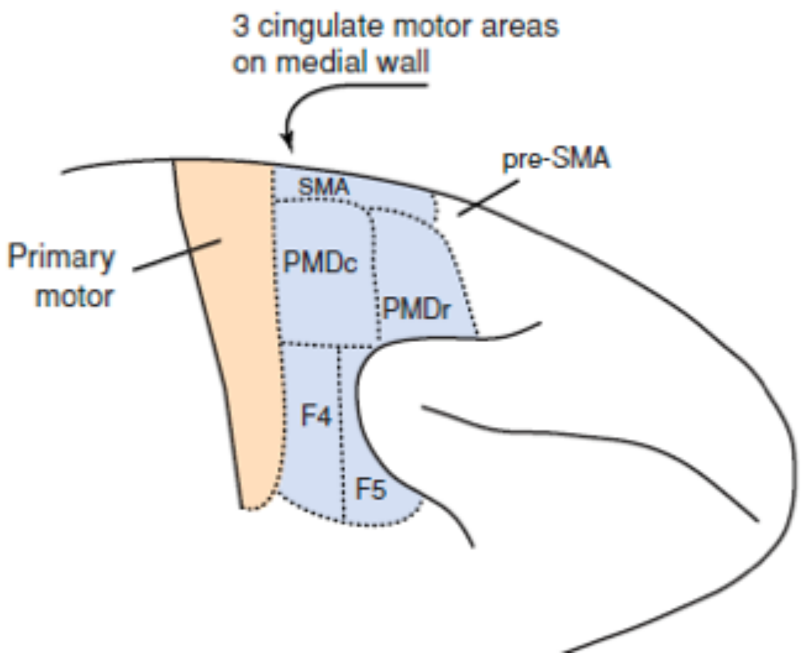
population code

- each neuron contributes its perferred direction as a vector, with length=its current firing rate
- vector sum=population vector predicts the movement direction

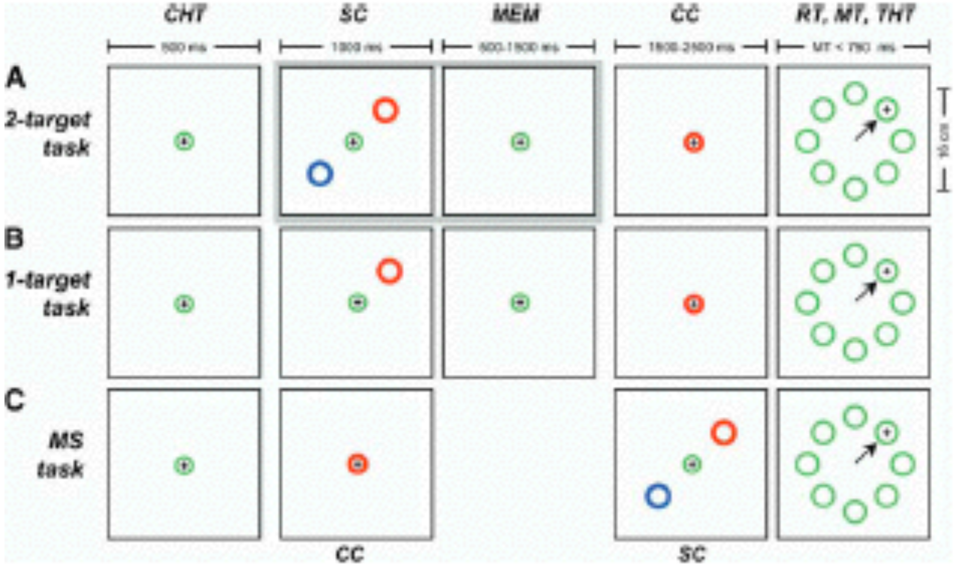


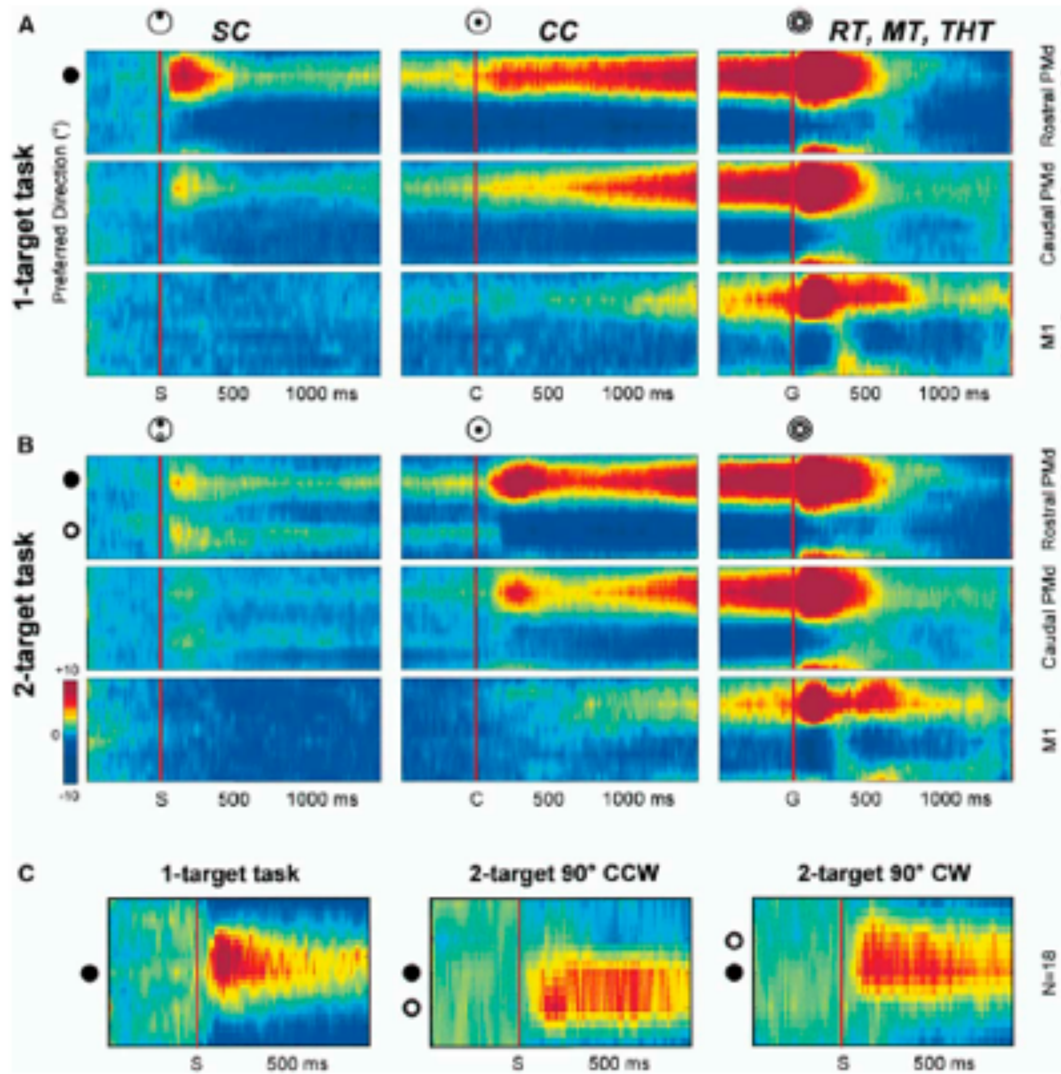
premotor cortices

- are involved in movement preparation



[Graziano, 2006]

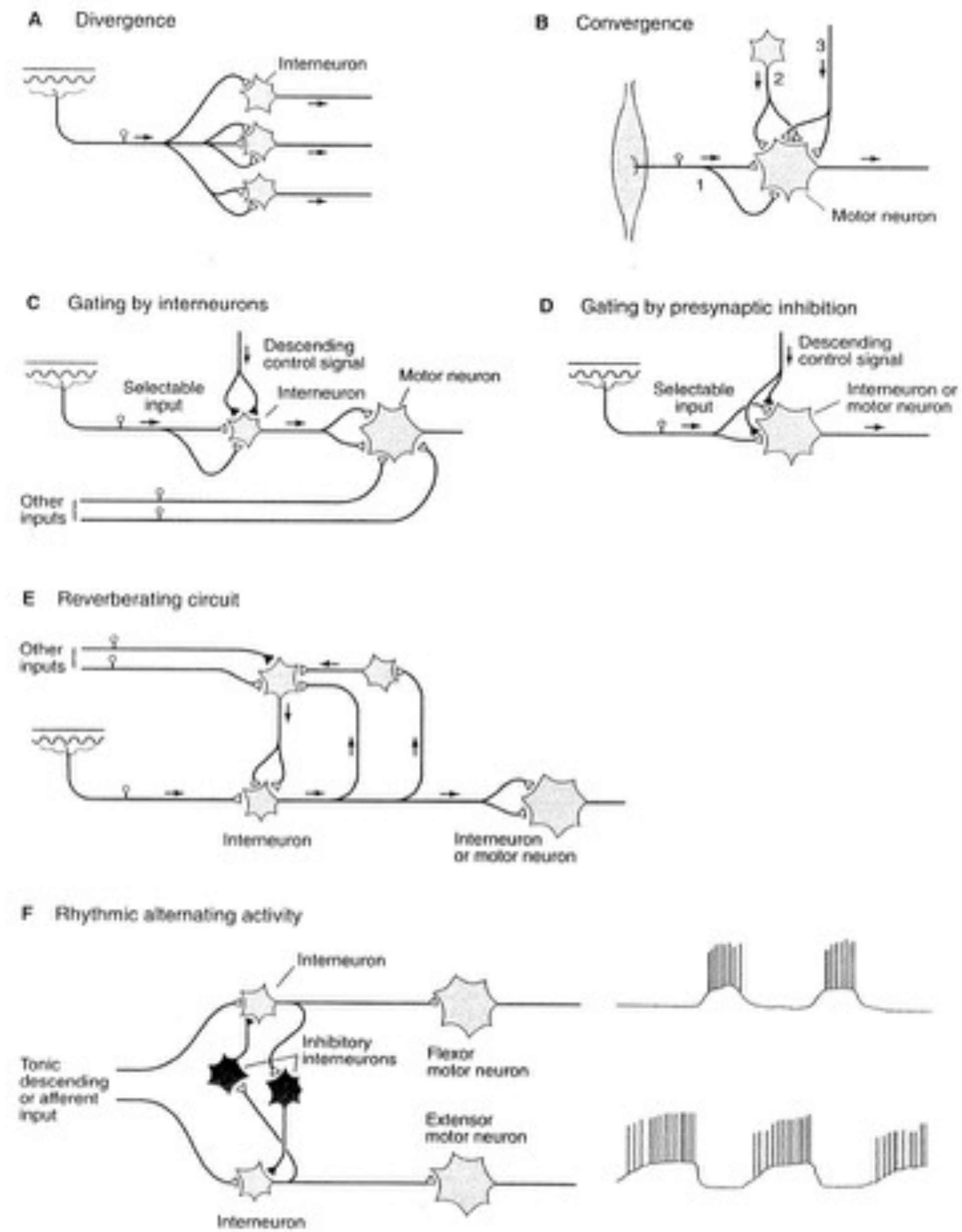




[Cisek, Kalaska, 2005]

spinal circuits: central pattern generators

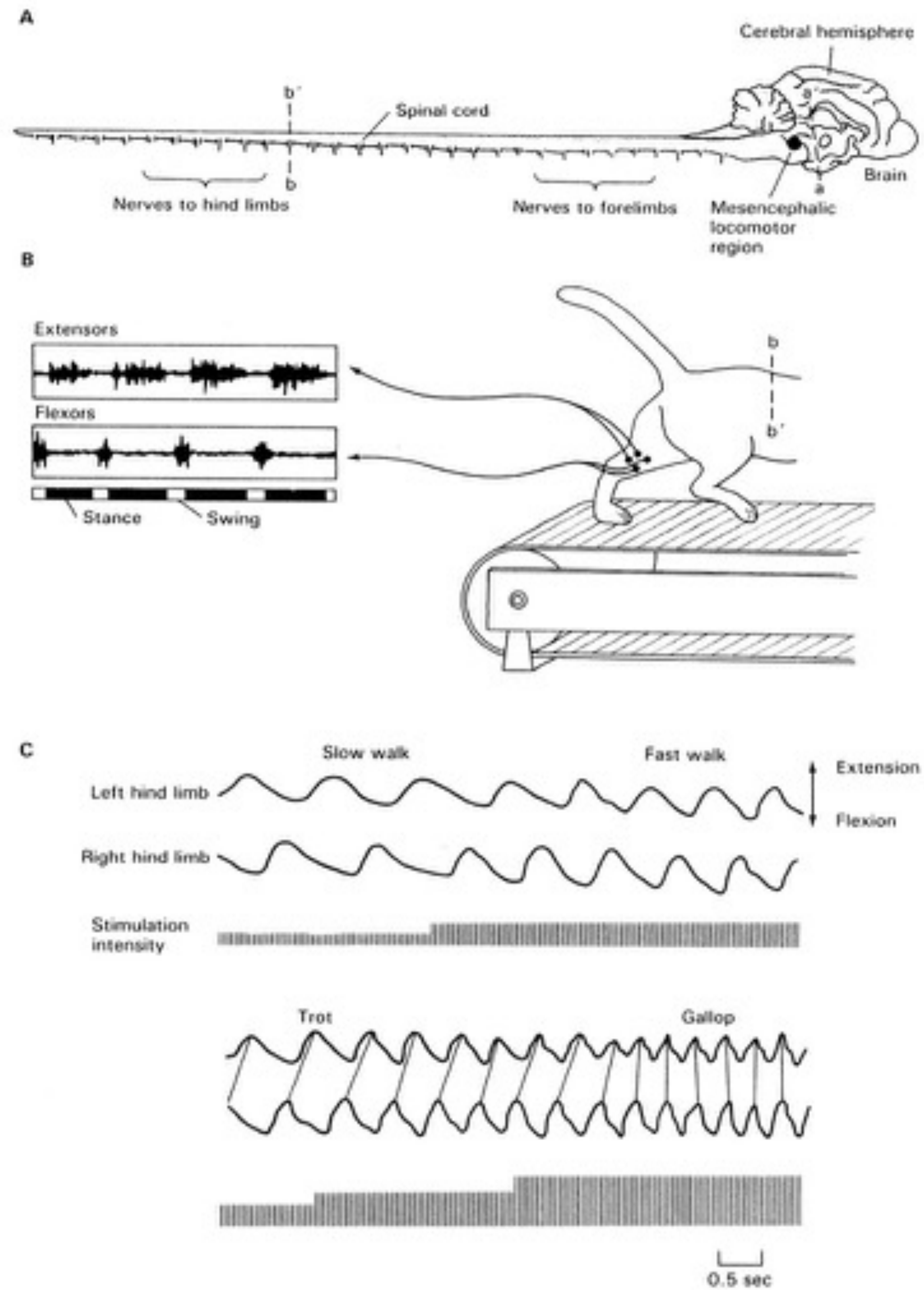
- spinal networks enable activation, deactivation, switching and self-stabilized oscillation
- with coordinated alternation between agonist and antagonist activation



[Kandel, Schartz, Jessell, Fig. 38-1]

CPGs generate rhythmic locomotory motor patterns

- descending signal from brain stem activates a intrinsic spinal pattern in cat



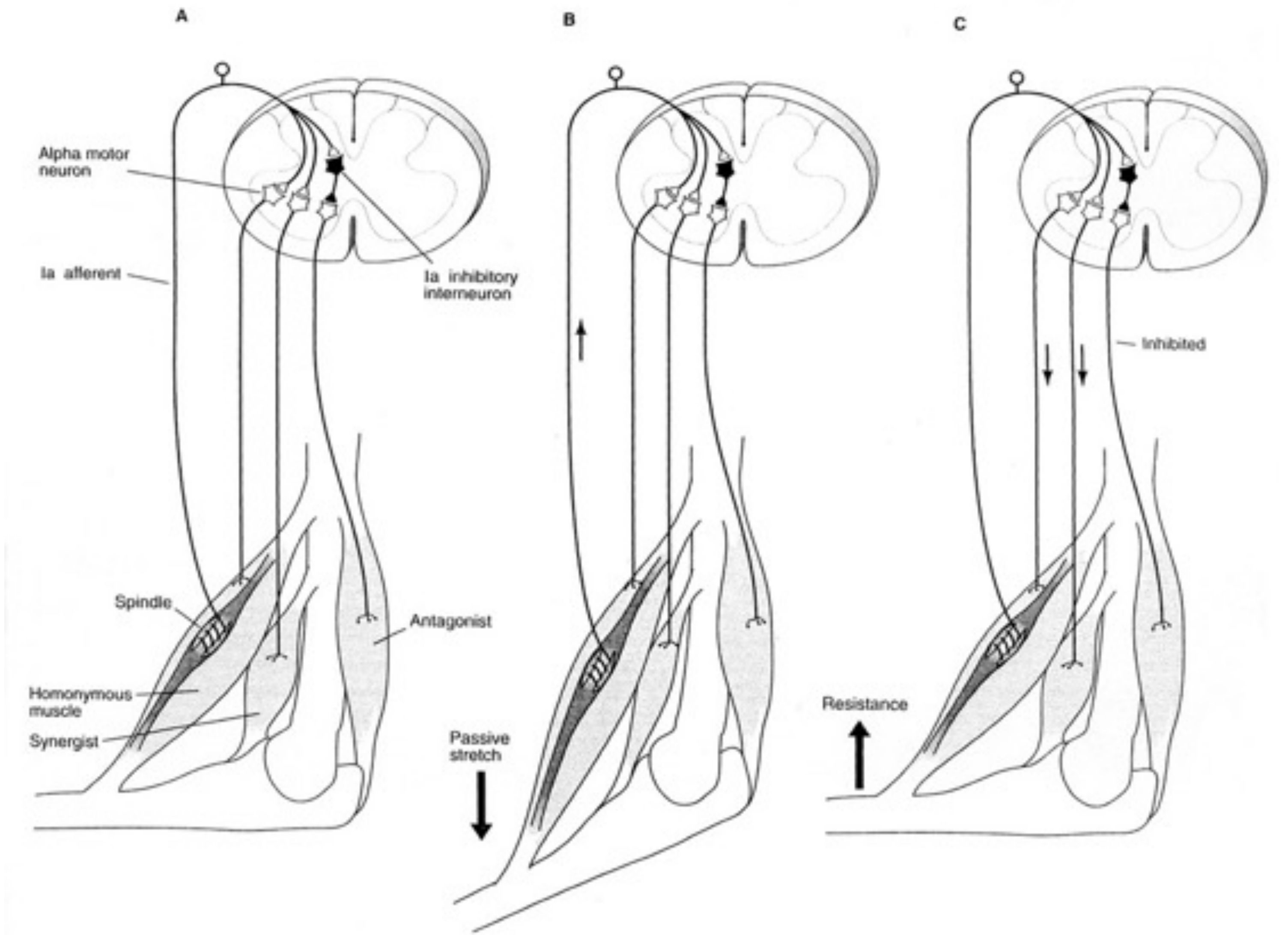
[Kandel, Schartz, Jessell, Fig. 38-9]

the brain stem

- the brain stem regulates/modulates spinal cord motor circuits
- in the control of posture, the brain stem integrates visual and vestibular information with somatosensory inputs
- brain stem nuclei control eye and head movements
- ...“old, basal” functions

spinal cord: reflex loops

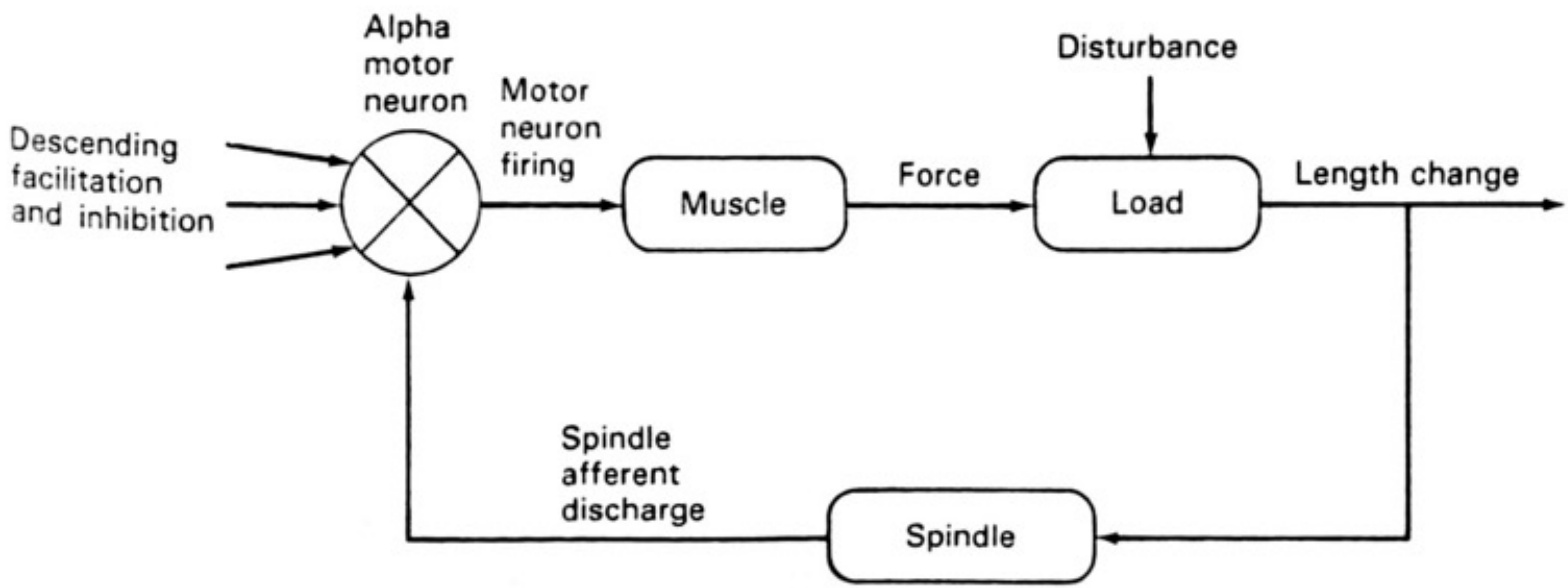
- alpha-gamma reflex loop generates the stretch reflex



[Kandel, Schartz, Jessell, Fig. 37-11]

spinal cord: reflex loops

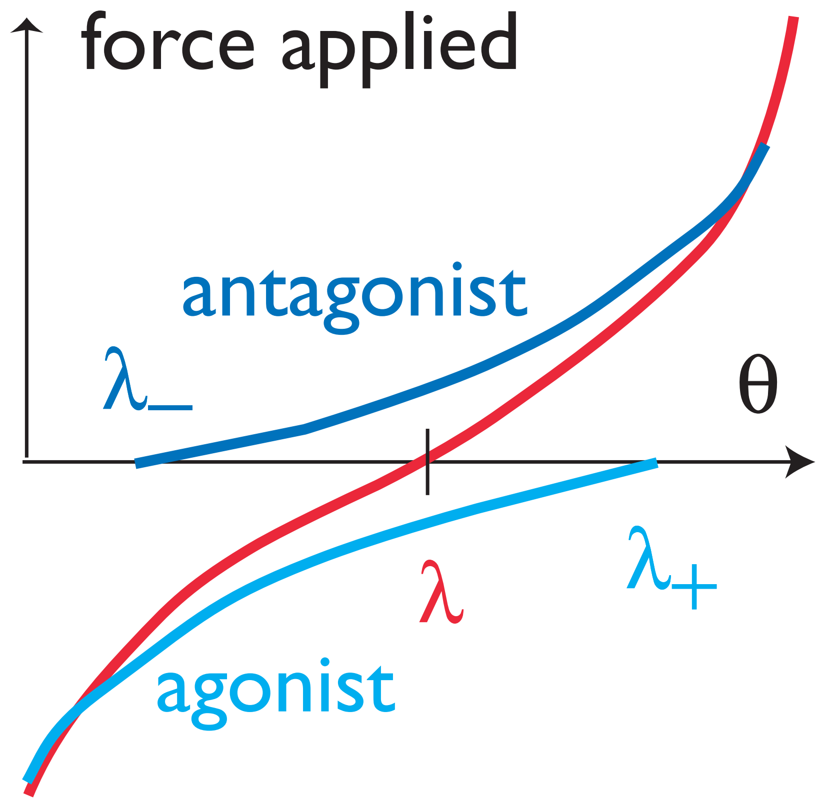
- the stretch reflex acts as a negative feedback loop



[Kandel, Schartz, Jessell, Fig. 31-12]

spinal cord: reflex loops

- as a result, muscles are "tunable springs"



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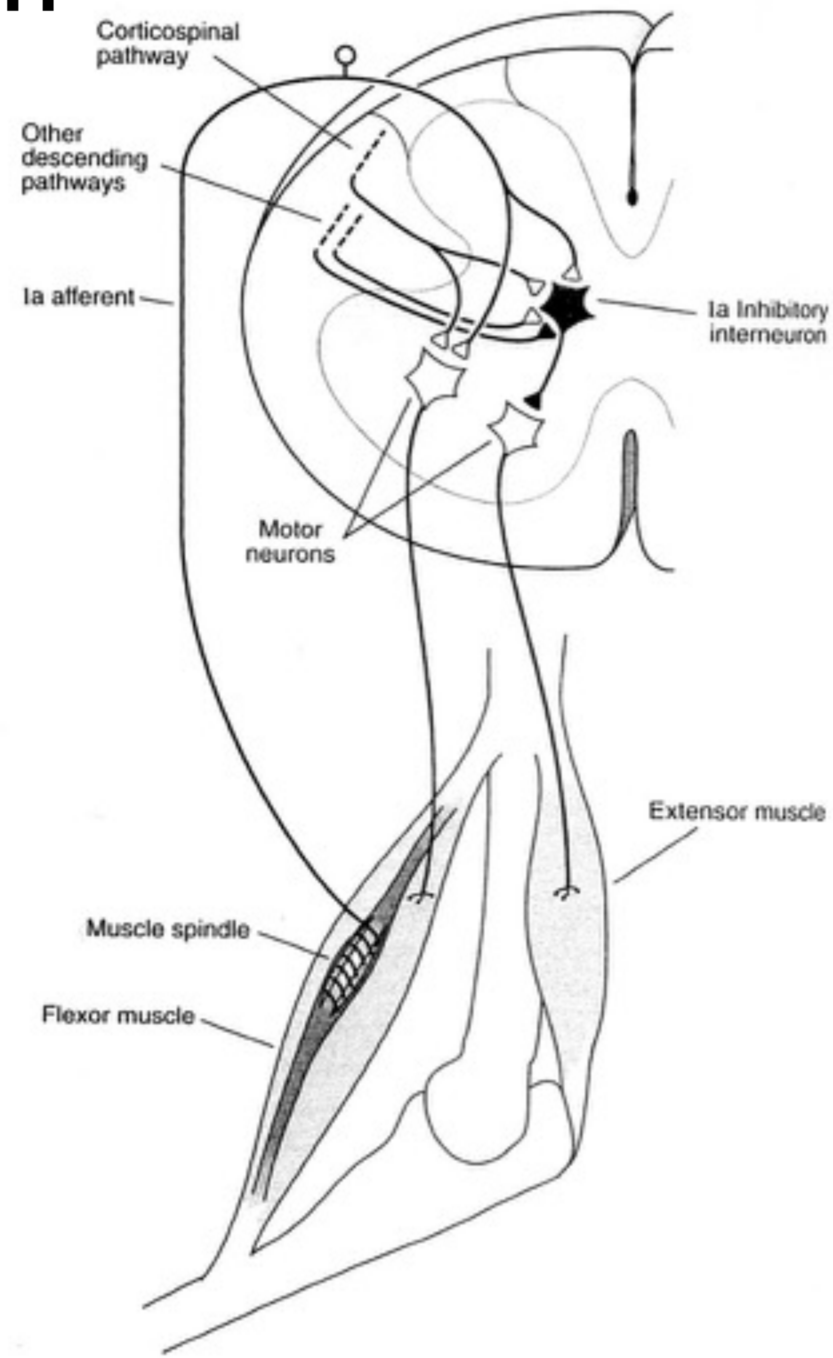
spinal cord: coordination

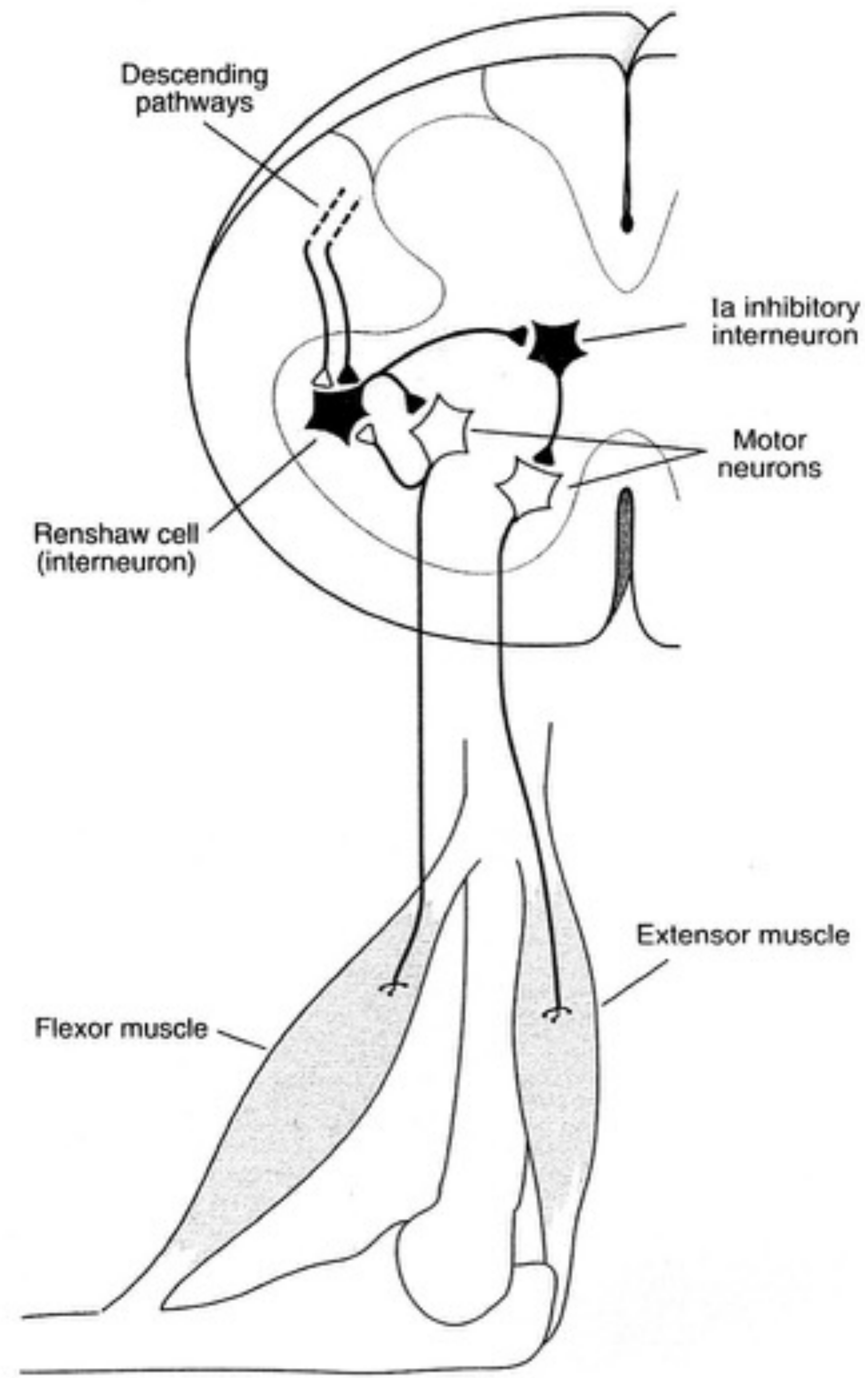
- Ia inhibitory interneuron mediates reciprocal innervation in stretch reflex, leading to automatic relaxation of antagonist on activation of agonist



[Kandel, Schartz, Jessell, Fig. 38-2]

spinal cord: synergies

- Renshaw cells produce recurrent inhibition, regulating total activation in local pool of muscles (synergy)



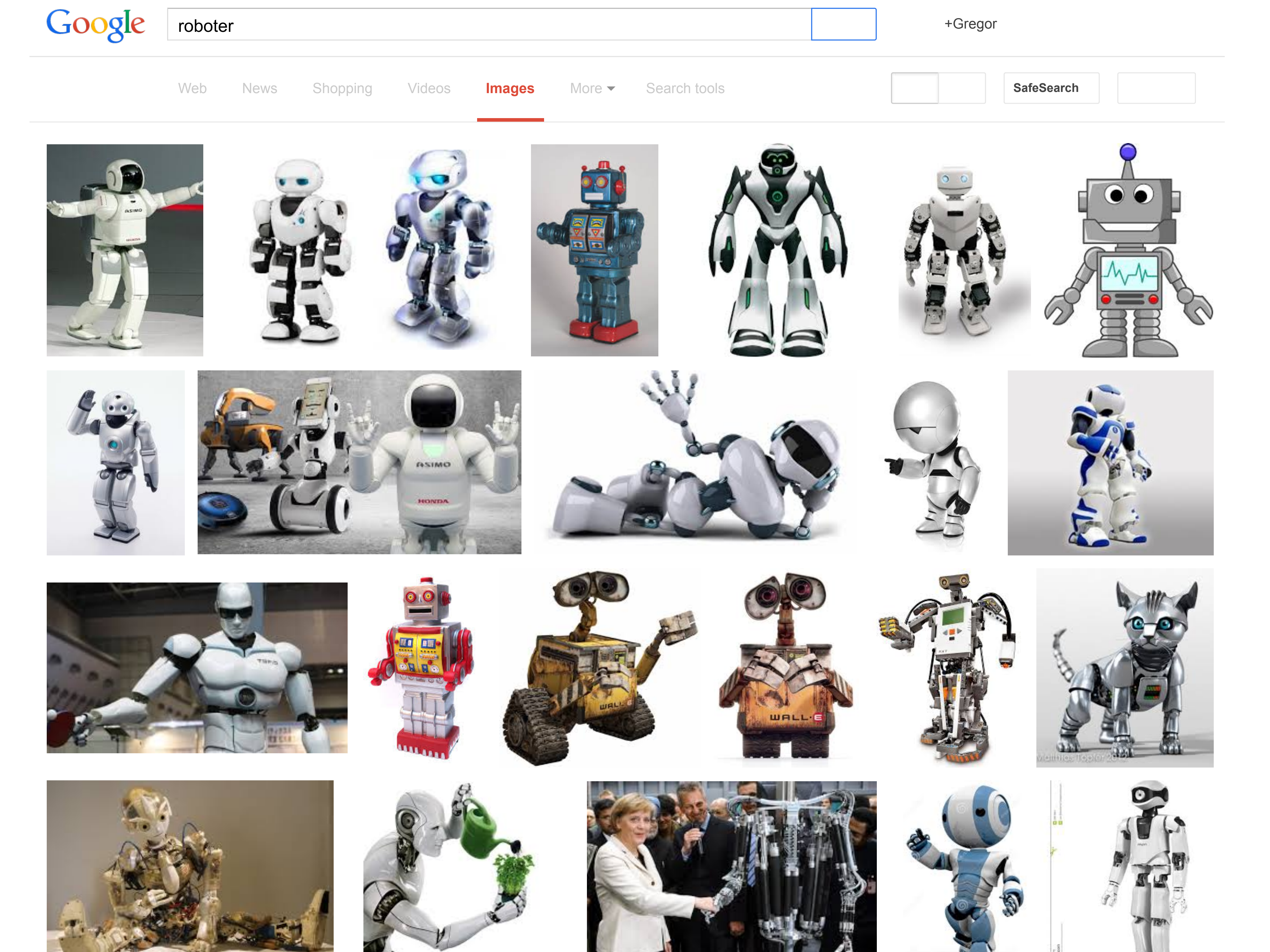
[Kandel, Schartz, Jessell, Fig. 38-3]

spinal cord

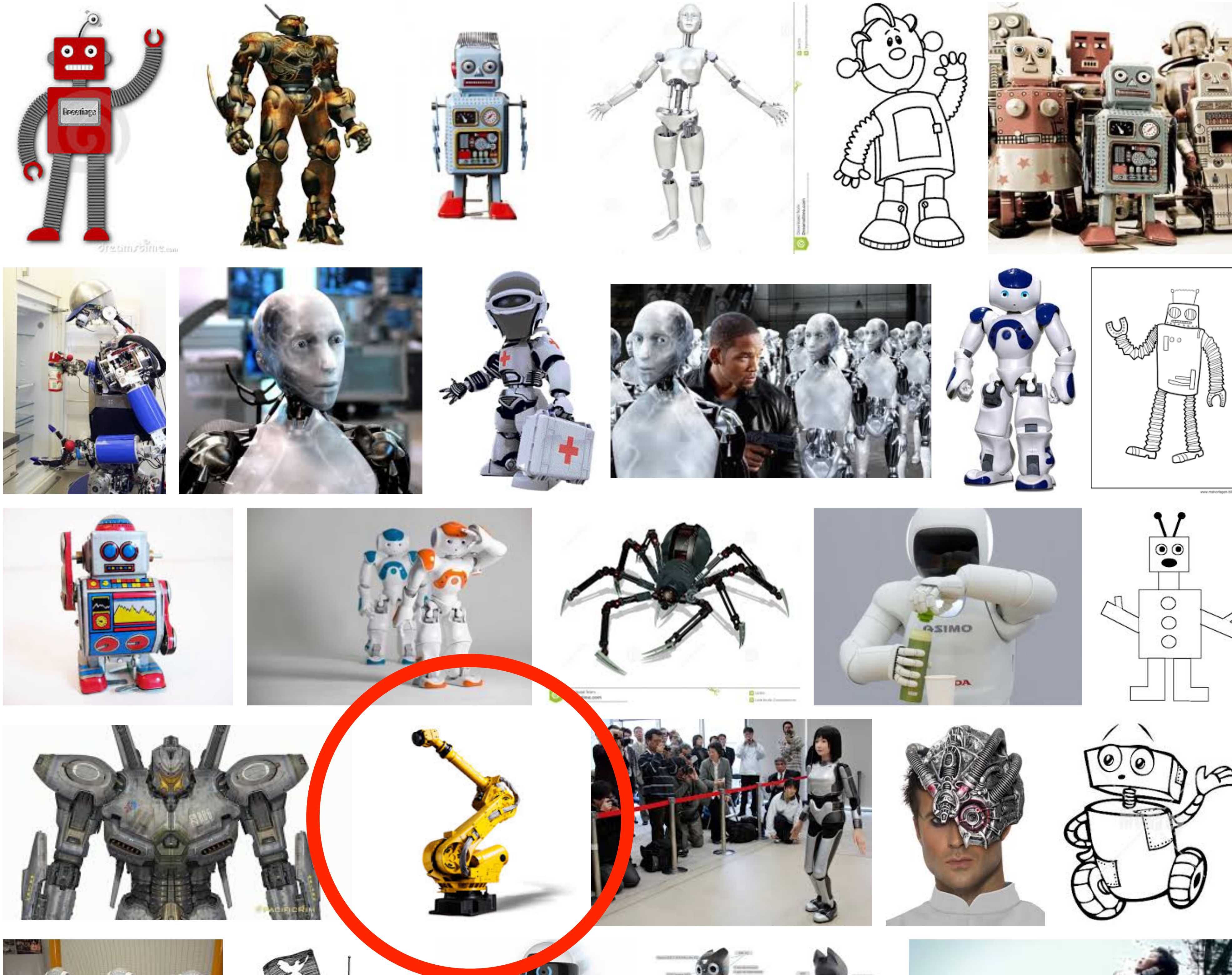
- => the periphery of the motor system contributes to movement coordination, timing, and control….

Robots

- Google search


roboter
+Gregor
Web
News
Shopping
Videos
Images
More
Search tools
SafeSearch
ASIMO
HONDA
WALL·E

=> Humanoids (or anthropomorphic) robots



industrial robots are actually more common today

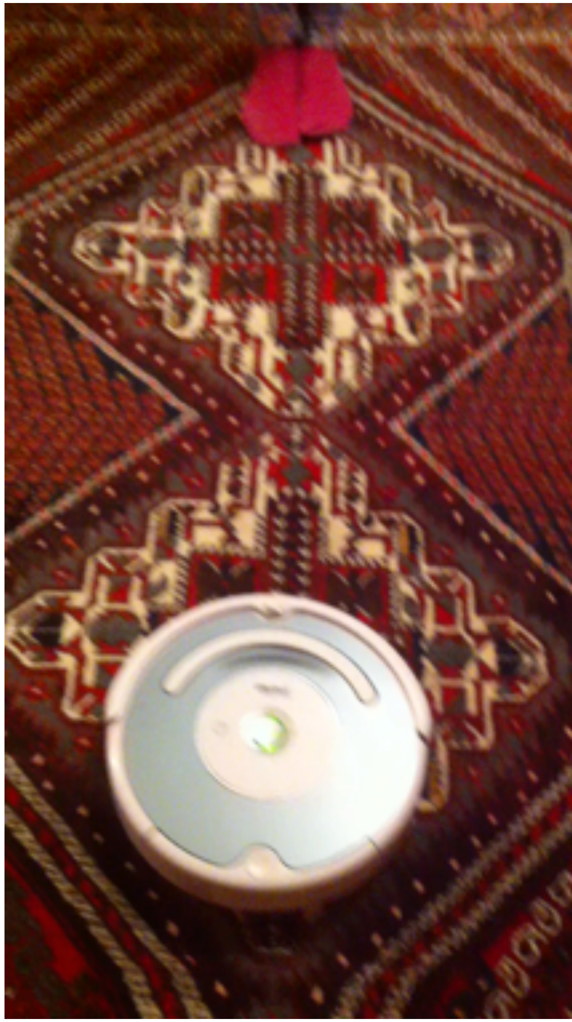
- fundamentally, all factory automatization is a form or robotics today: “programmable” machines…

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

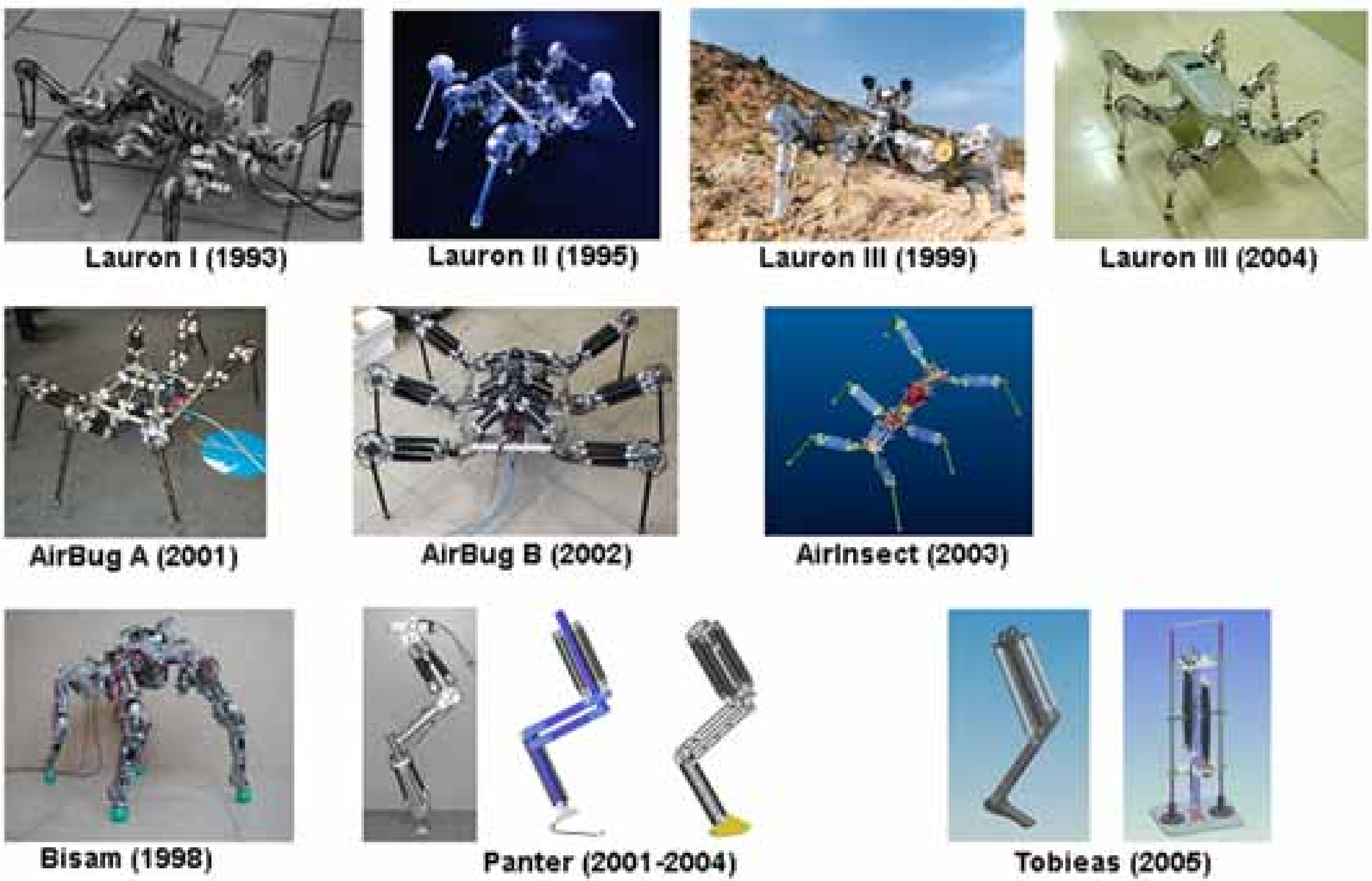


Figure C.58. The walking machines built by Dillmann's group.

snakes, crawlers, climbers

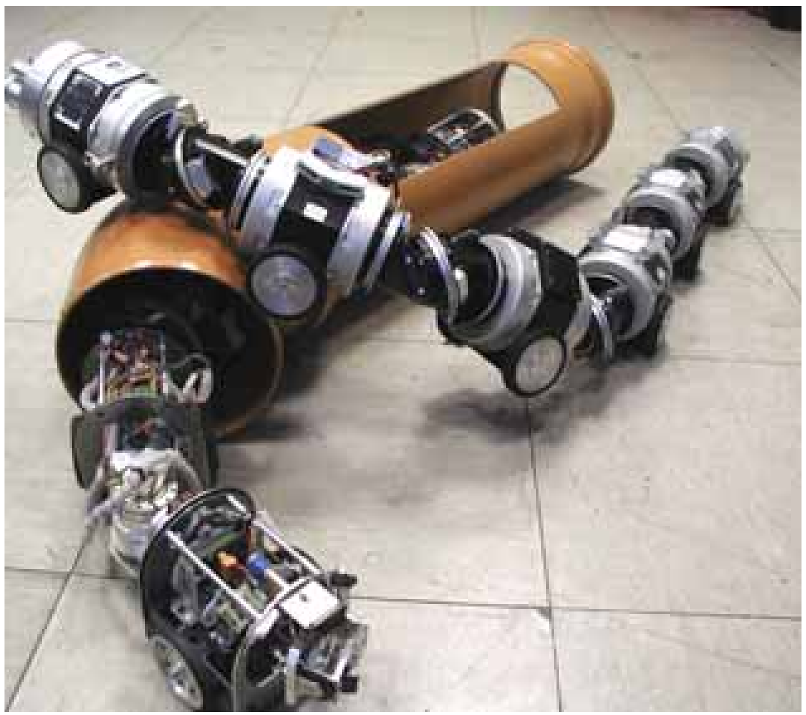


Figure C.57. Inspection robot.

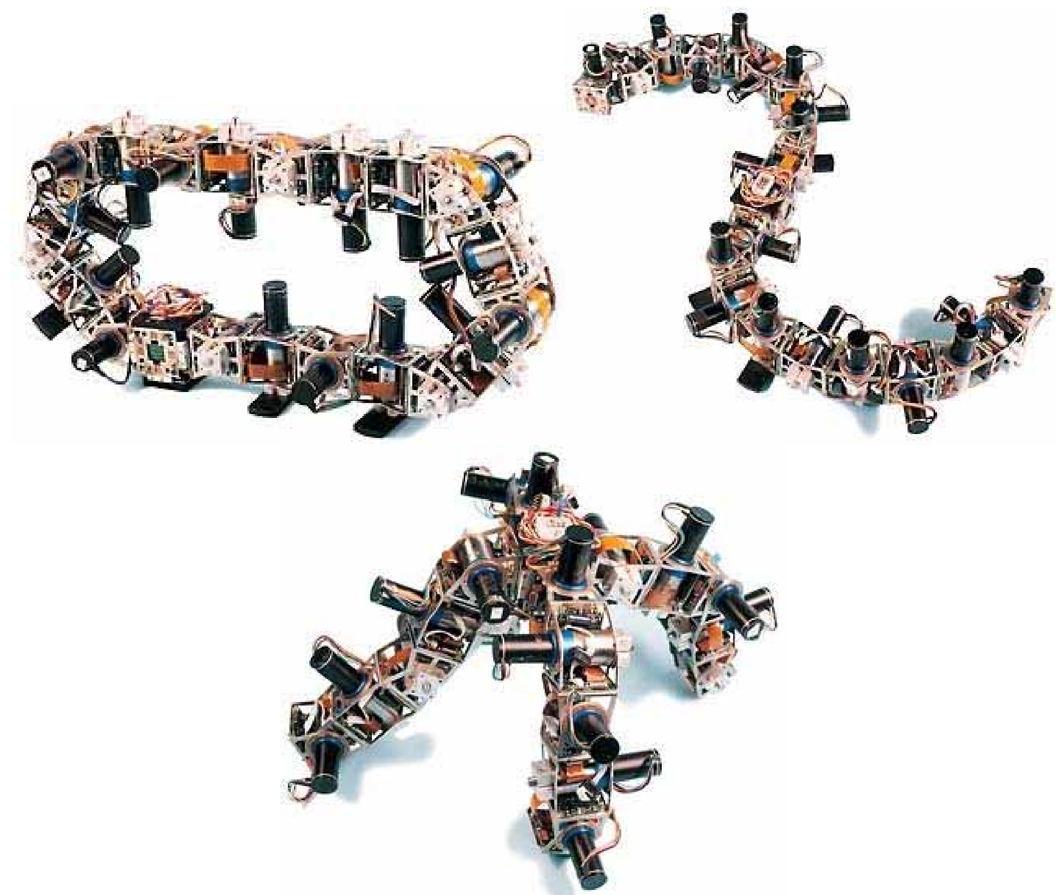


Figure 7.2. Robotic modules can be reconfigured to "morph" into different locomotion systems including wheel-like rolling system (left), a snake-like undulatory locomotion system (right), a four-legged walking system (bottom).

underwater vehicles, ships

Figure 2.2. IFREMER ASTER autonomous underwater vehicle.

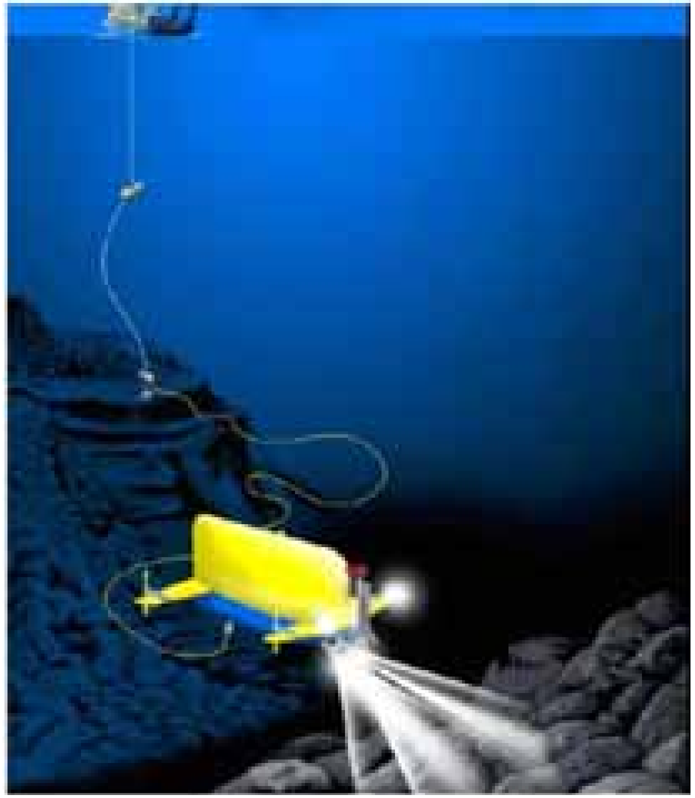
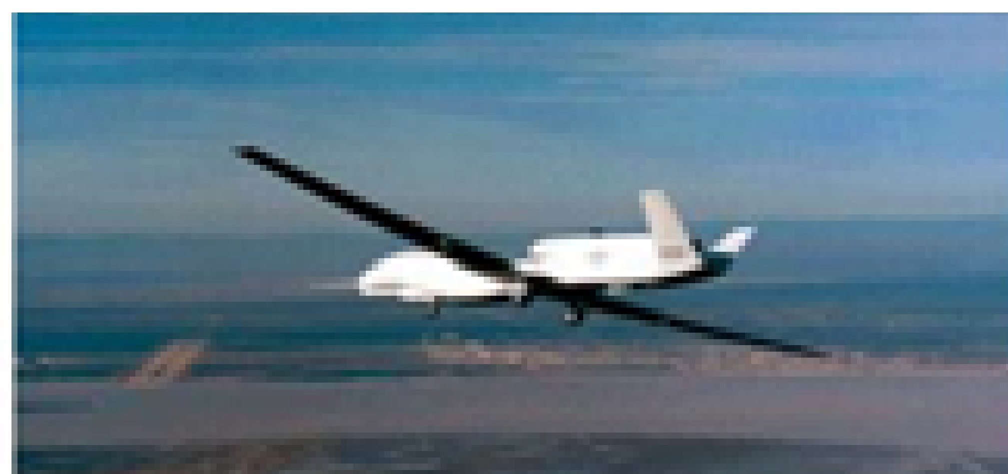


Figure 2.11. HROV (Hybrid ROV) project (Johns Hopkins University (JHU) and Woods Hole (WHOL), U.S.).

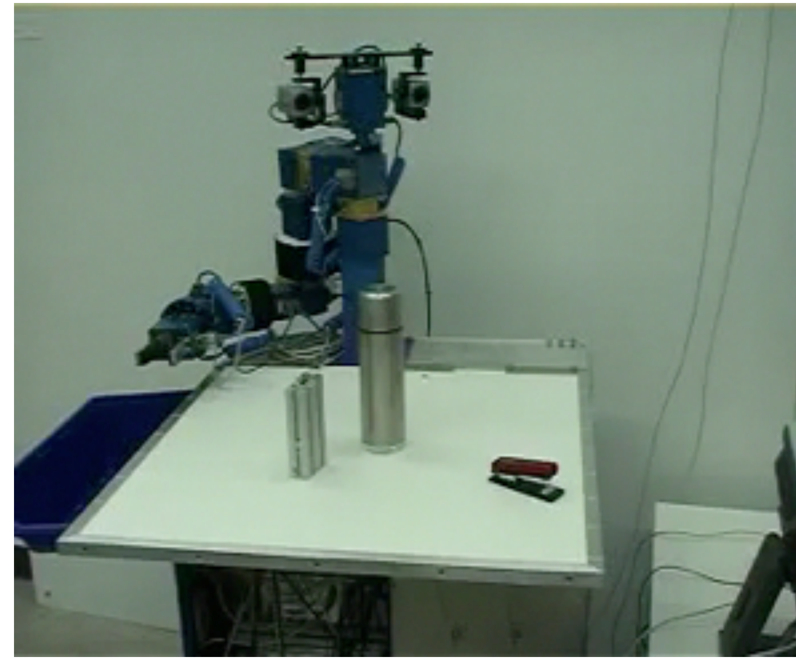
airborne robots

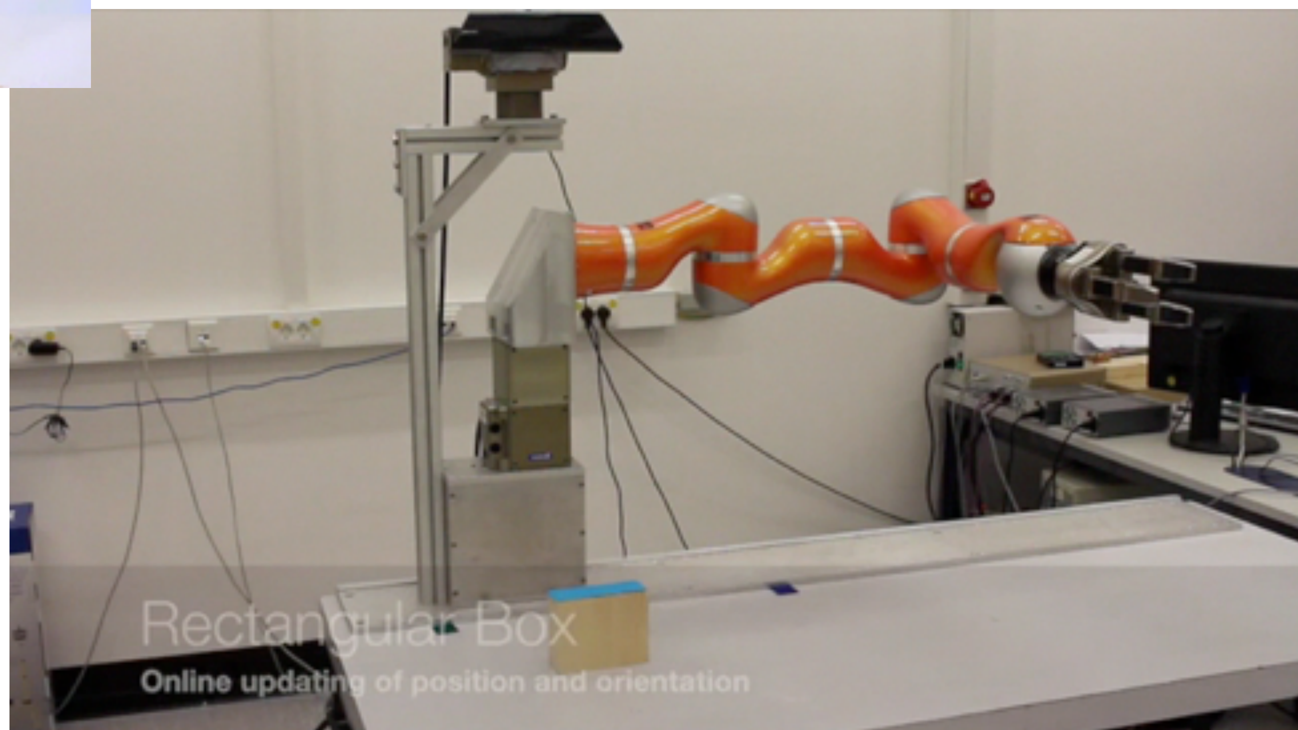


robotic manipulators, hands

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

some of our own robotic manipulators

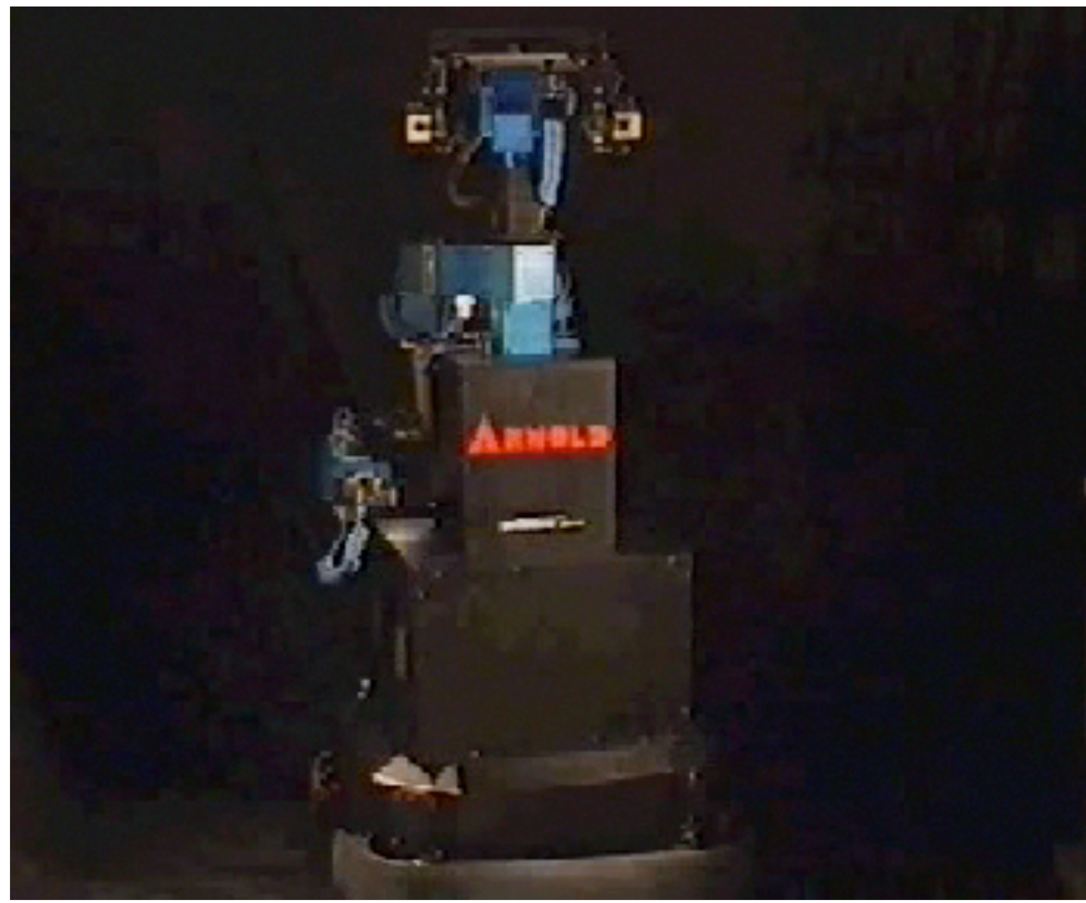




mobile robot manipulators

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

our own mobile robot manipulator



[Arnold: 1998-2000]

In this course

- we will refer to
  - vehicles
  - robotic arms with a vision sensor

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 19 year old son…
  - “I don’t know, to clean up, to serve drinks … but they are just generally cool /…
  - … (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

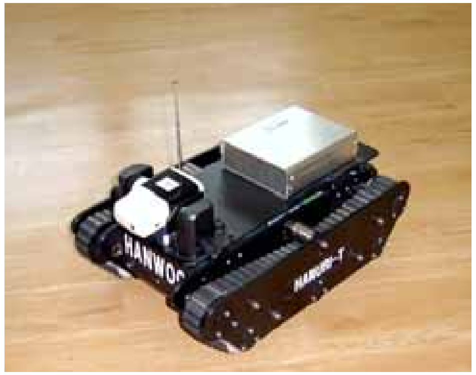
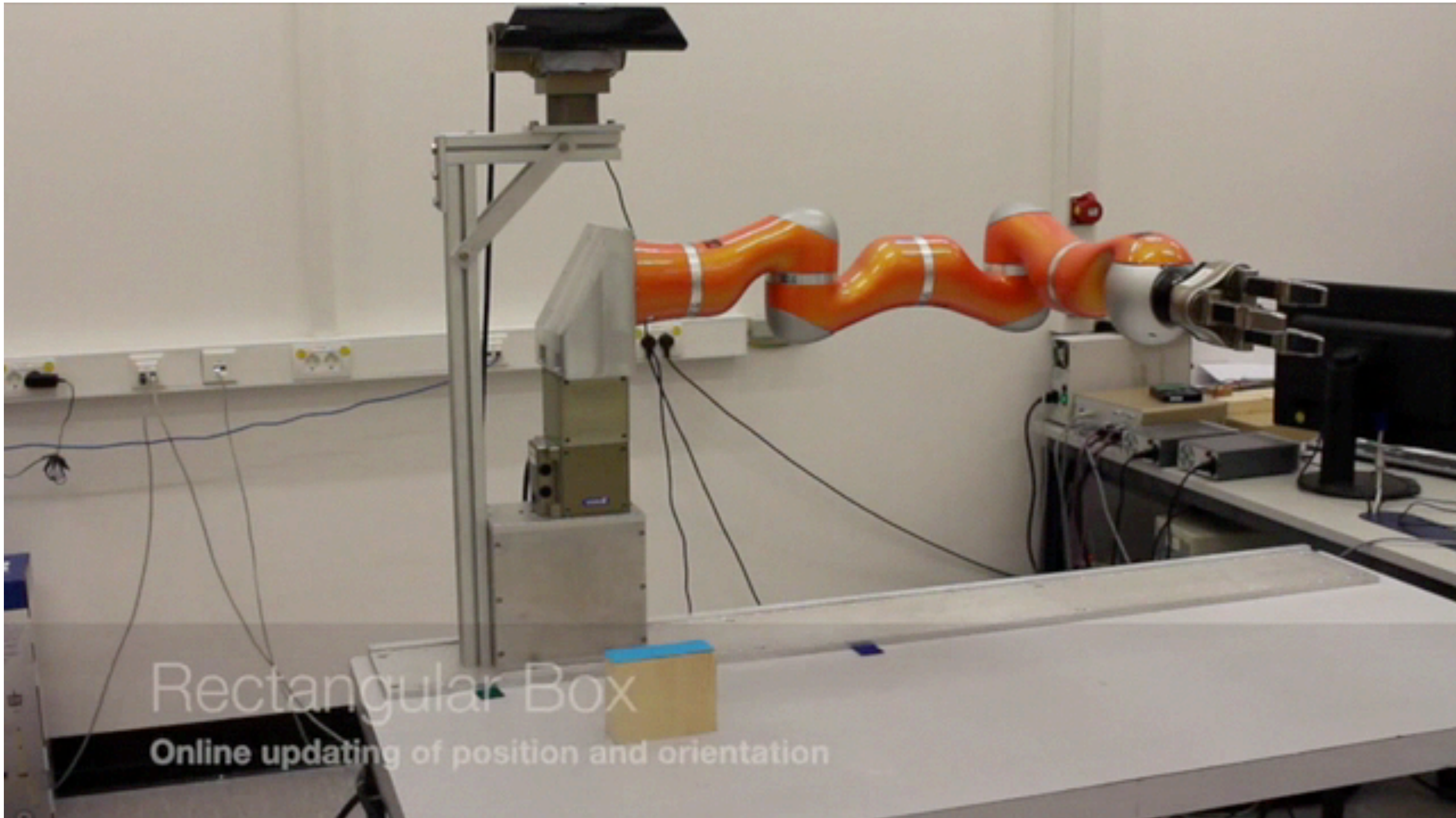


Figure B.11. Military Robot.

(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 models systems, treating the remainder stochastically…. autonomous robotics act in natural environments that are difficult to model
- autonomous robotics: highly interdisciplinary
- modern engineering uses modular design,that limits the range over which modules interact/interfere…autonomous robotics: requires system integration

robotics vs. human movement

- shared functions, constraints
- standard approaches are very different
  - but we will look at neural principles that can be used to build autonomous robots
- the motor control problem is very different:
  - servo-control with very high stiffness/precision vs. soft spring-like control in humans
  - but: interest in compliant robots
  - e.g., grasping, changing the demands on perception by using spring-like actuators

autonomous robots as demonstrations of neural function

- neural process models: capable of generating the modeled behavior based on real or simulated sensory information …
- proof of function as a source of heuristics
  - discover problems that are often overlooked
  - the problem of synthesis or integration…
  - discover non-problems that need not be solved to achieve a function