Autonomous Robotics: Action, Perception and Cognition: Introduction

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

- Google search “robot” (21 apr 2020)

Nao (robot) - Wikipedia
en.wikipedia.org

more productive than human workers ...
information-age.com

Future Robots and Ensuring Human S...
blogs.3ds.com

Robots have jumped, raced and rolled a ...
cnet.com

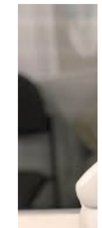
H
b

fight the coronavirus in China ...
businessinsider.com

Social robot - Wikipedia
en.wikipedia.org

China says AI robots won't lead to ...
techinasia.com

Could robots be marking your homework ...
bbc.com



CES 2020 v
cnet.com

Humanoid robot job apocalypse — or a ...
pri.org

Here are the coolest robots of 2019 s...
thegadgetflow.com

extend the scope of IoT applications ...
networkworld.com

The time for putting up with stupid ...
cosmosmagazine.com

Eight cute and
dezeen.com

Japanese-Israeli venture offers robots ...
timesofisrael.com

Robots Might Make Human Workers More ...
bloomberg.com

NAO the humanoid and pro...
softbankrobotics.com

Will Robots Rob Us From Our Jobs?
industrywired.com

Robots.txt Datei fürs SEO ...
neilpatel.com

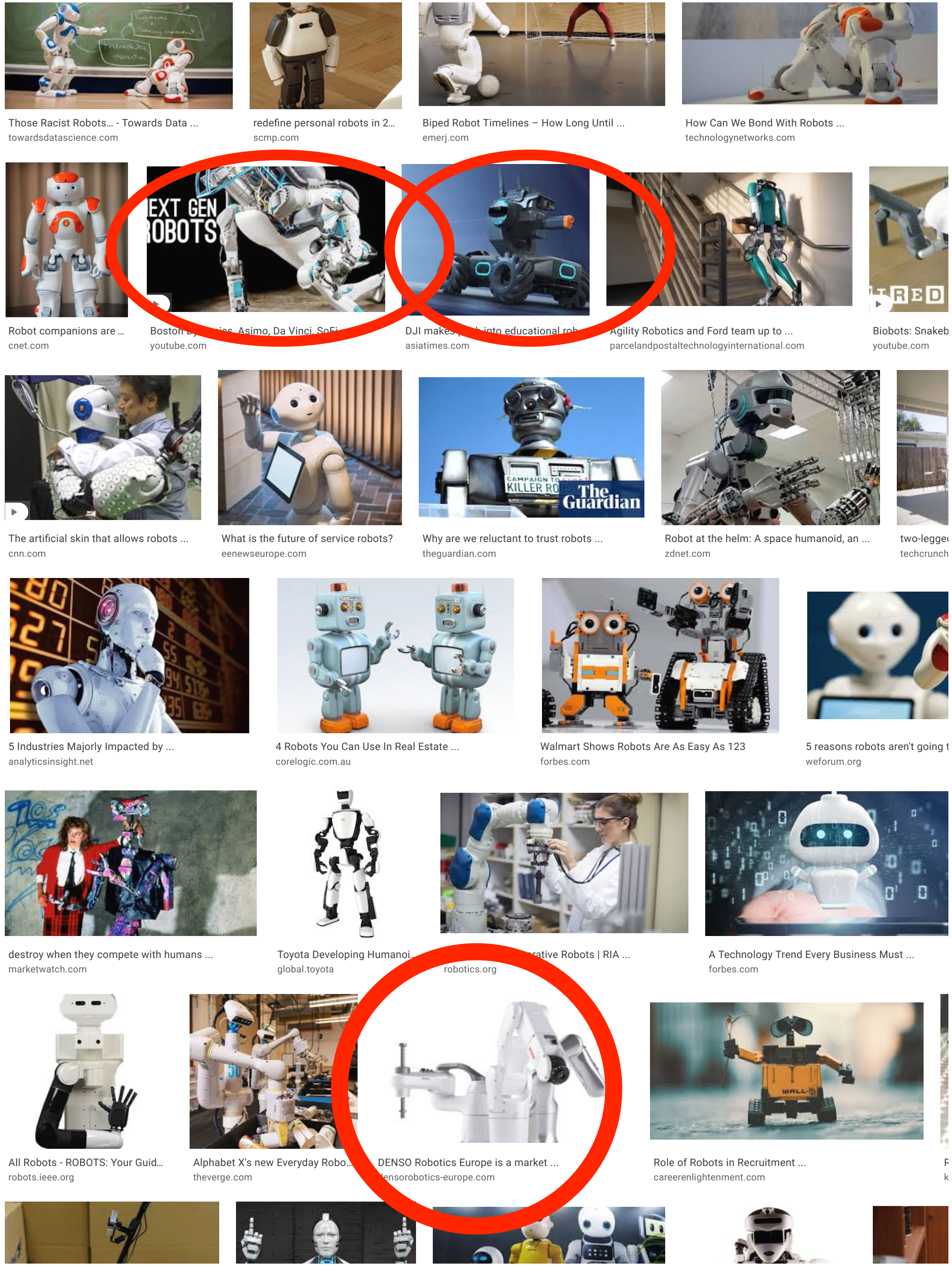
Why Ethical Robots Might Not Be Such...
spectrum.ieee.org

Robots could learn to recognise human ...
techxplore.com

Russia and robots: Steel junk or a ...
bbc.com

=> Humanoids (or anthropomorphic) robots page 2

legged robot



vehicle

compliant arms

no regular industrial robot on first 4 pages

Industrial robots

- in reality, industrial robots are much more common today than humanoids, or autonomous robotic vehicles
- fundamentally, all factory automatization is a form of robotics: "programmable" machines…= flexible machines

Autonomous robotics

- industrial robots are programmed in a fixed and detailed way based on information about the world available to the programmer
- *auto-nomos*: giving laws to oneself:
- => autonomous robots generate behavior based on sensory information obtained from their own on-board sensors

Autonomous robotics

- aligned with the vision of AI:
  - Russell, Norvig (2020): "The main unifying theme is the idea of an intelligent agent. We define AI as the study of agents that receive percepts from the environment and perform actions"

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

- opposite limit case: autonomous robots are not totally autonomous to do “whatever they want”…
- must receive “tasks”, instructed by “commands”

Autonomous robotics

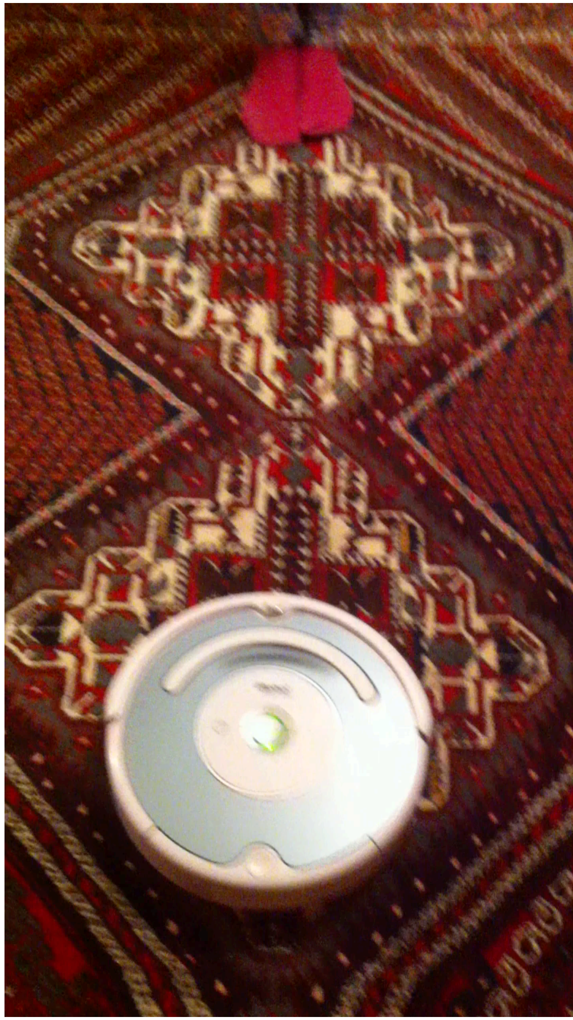
- autonomy as an programming *interface*:
- give goals to a robot at a high level, using human language and gesture in a shared environment…
- the autonomous robot then deals with the details of how to achieve those goals…

[Ioannis Iossifidis at the INI]

Some examples of (mostly autonomous) robots

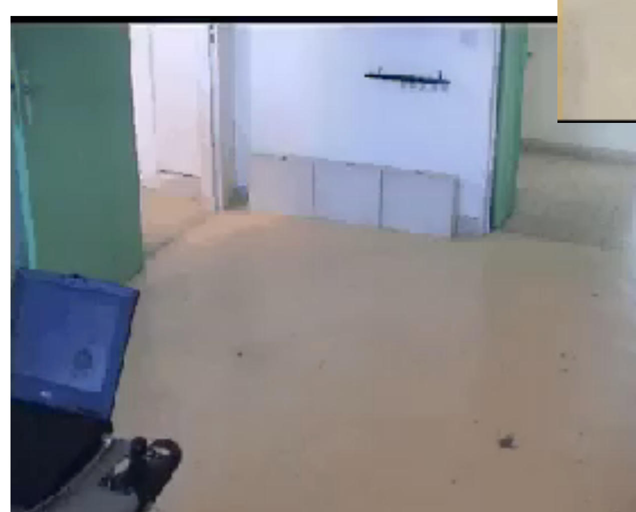
Simple, single-task autonomous vehicles

Figure 5.5. Examples of service robots.



[photo credits: WTEC final report 2006]

Some of our own (older) 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

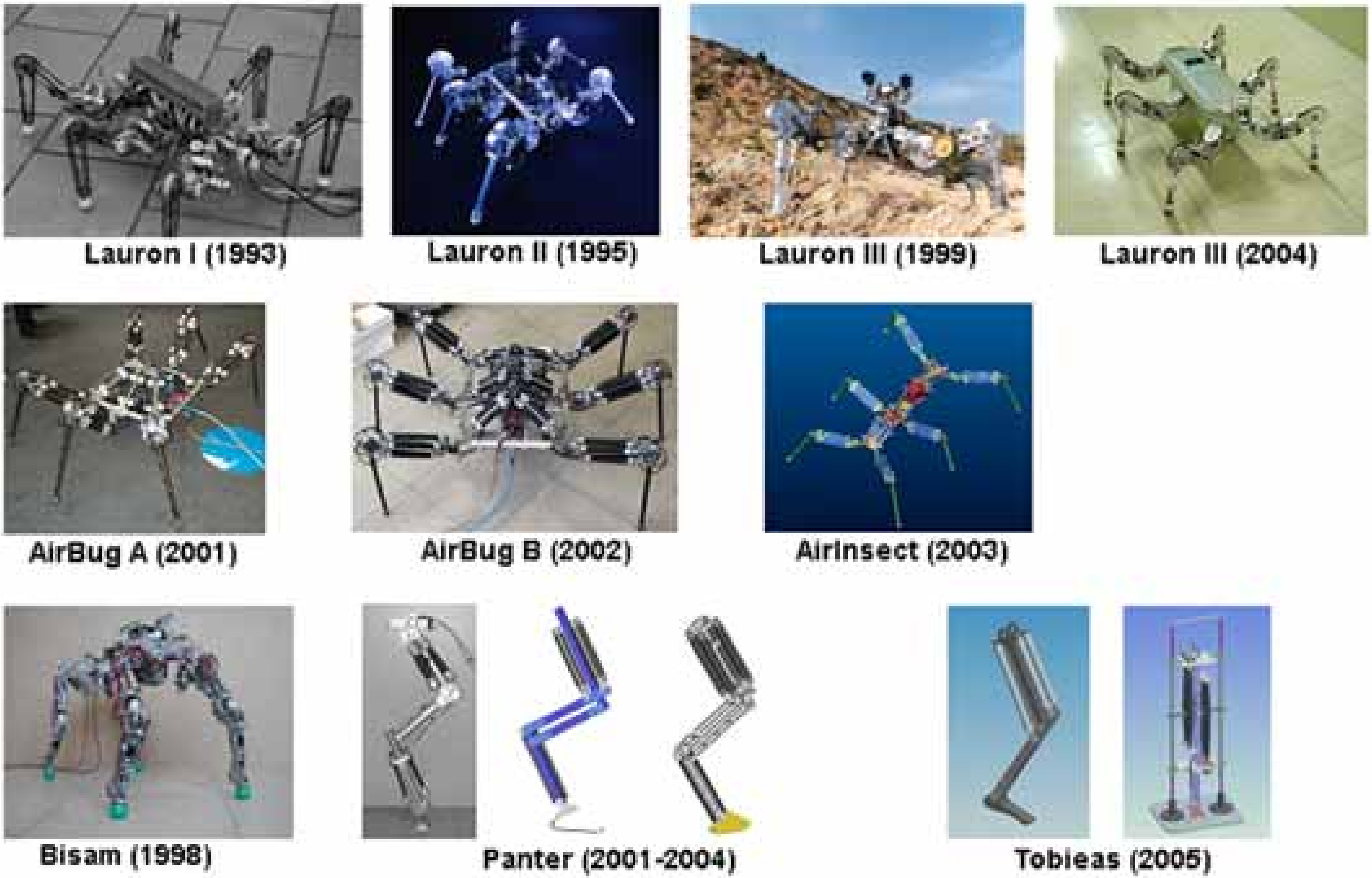
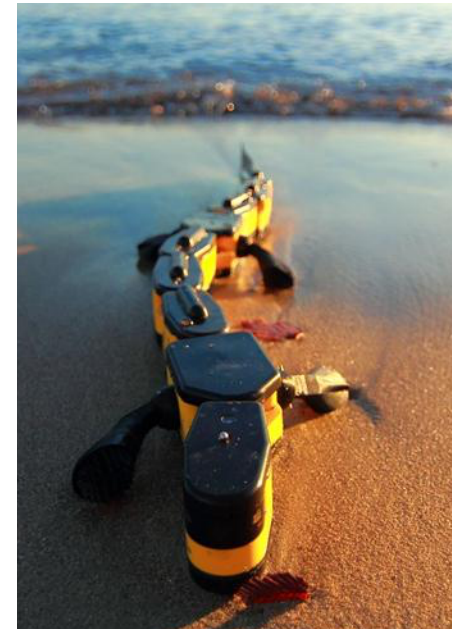
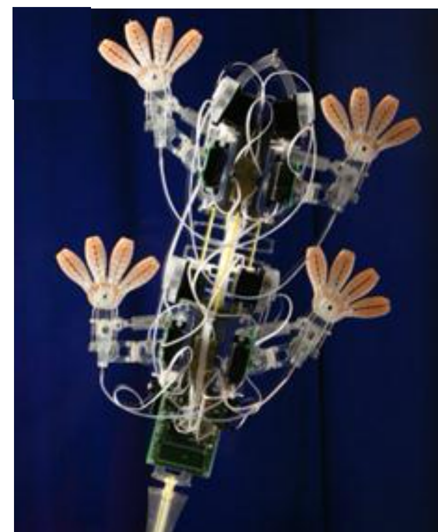


Figure C.58. The walking machines built by Dillmann's group.

Biologically inspired robots





Snakes, crawlers, climbers

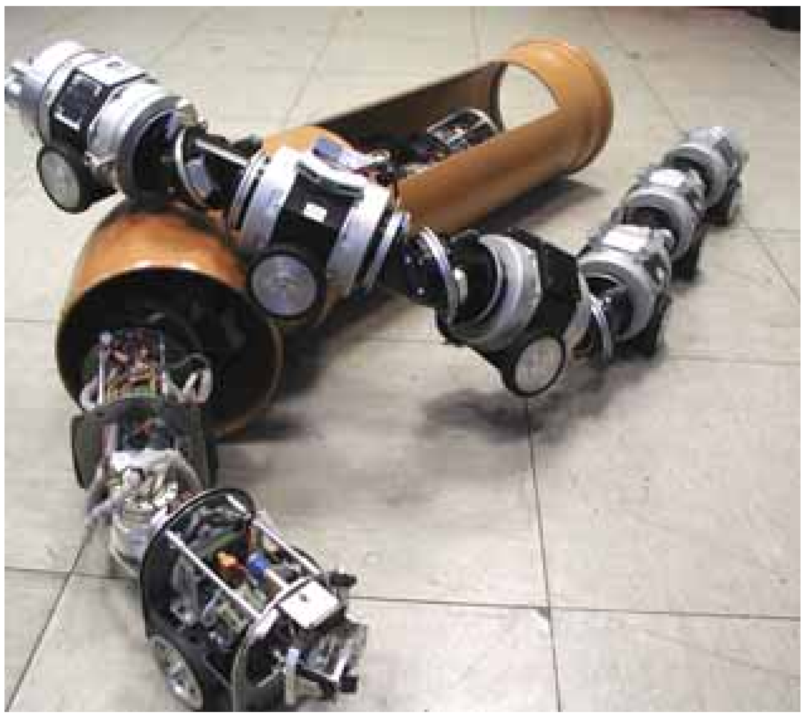


Figure C.57. Inspection robot.

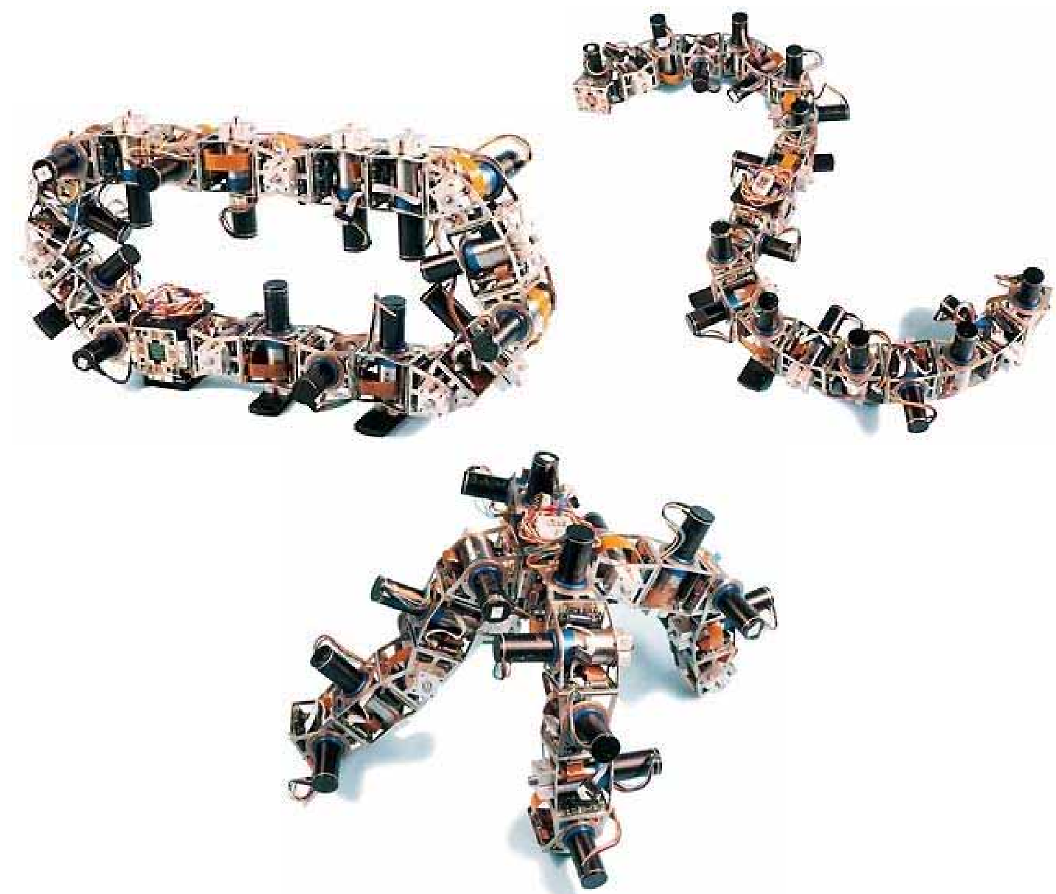


Figure 7.2. Robotic modules can be reconfigured to "morph" into different locomotion systems including wheel-like rolling system (left), a snake-like undulatory locomotion system (right), a four-legged walking system (bottom).

Surface and underwater naval drones

Figure 2.2. IFREMER ASTER autonomous underwater vehicle.

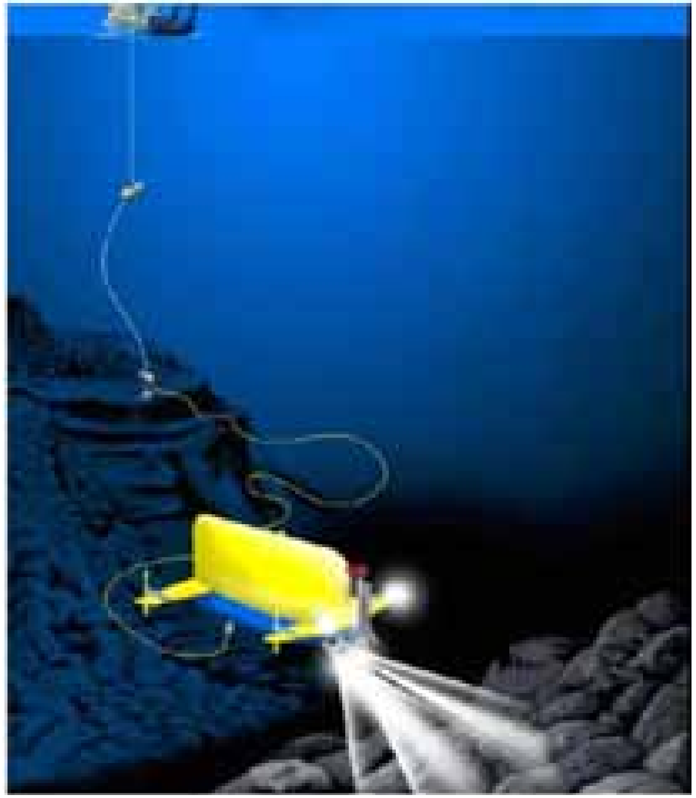
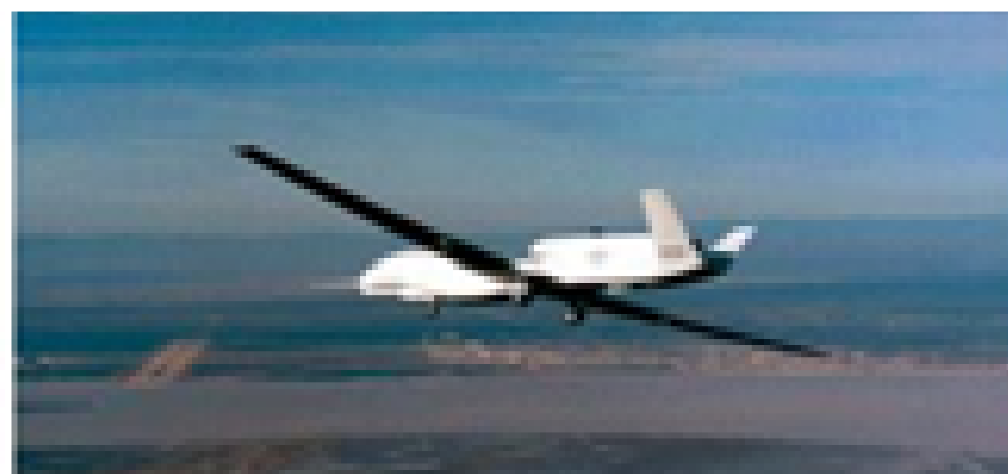


Figure 2.11. HROV (Hybrid ROV) project (Johns Hopkins University (JHU) and Woods Hole (WHOL), U.S.).

Airborne robots (drones)



Robotic manipulators, hands

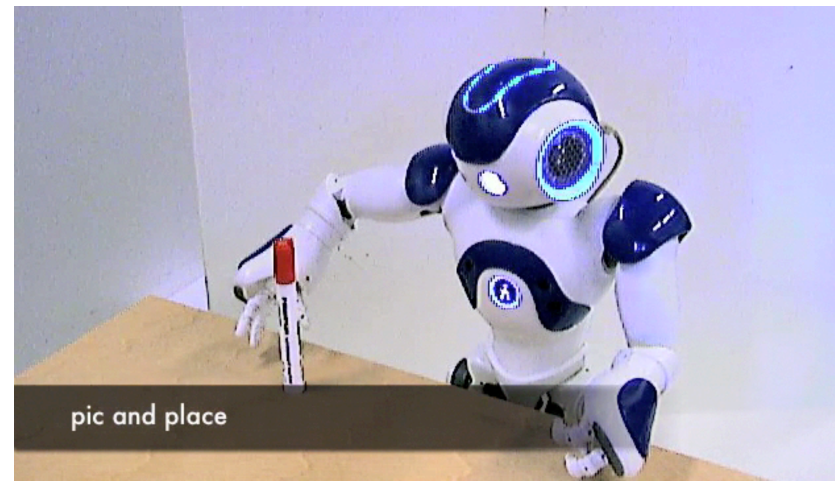
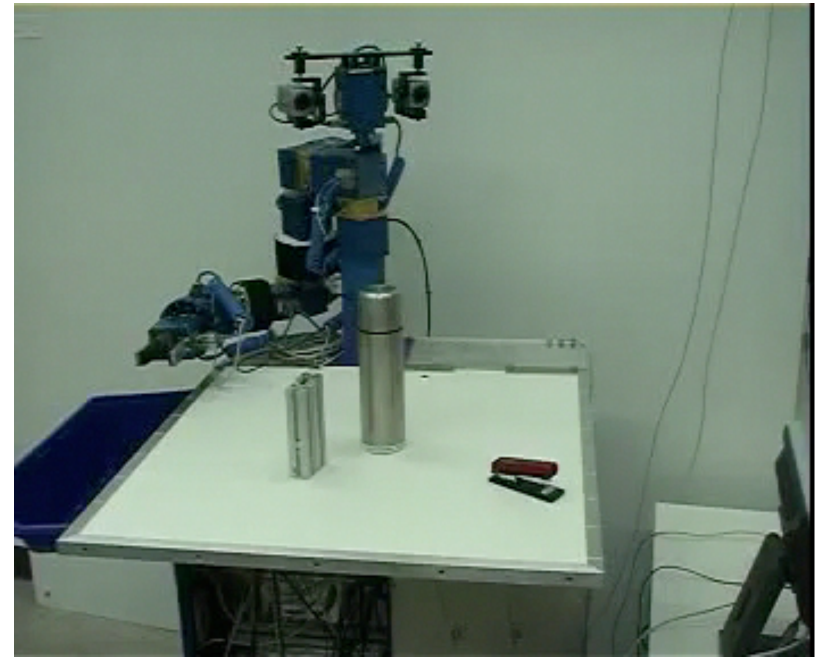
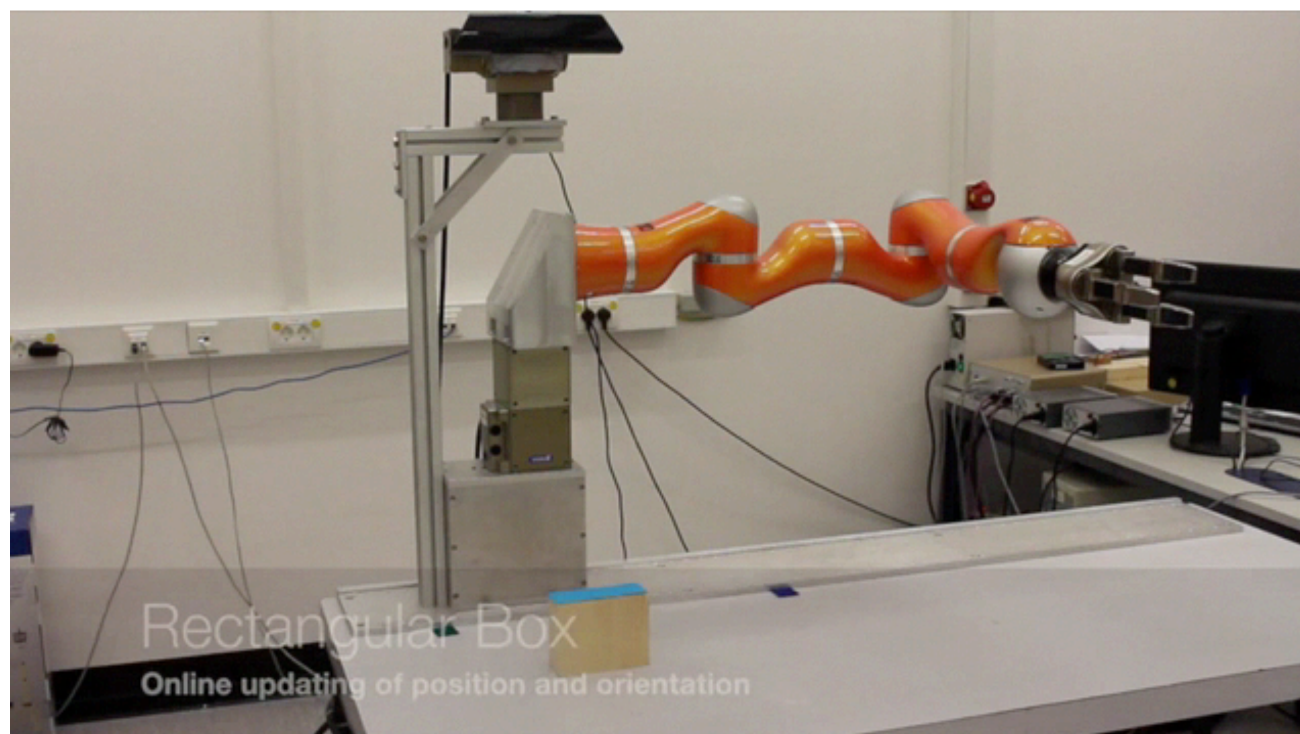


Figure 4.10. Dexterous arms at DLR, NASA and UMASS.

Some of our own robotic manipulators





Mobile robot manipulators

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

[Arnold: 1998-2000]

Why autonomous robots?

- ideas I tend to hear from people …
  - just generally cool..
  - to clean up, to serve drinks..
  - robot soldiers..

Toys/entertainment/animation

- including therapy (autism)

Assistance robotics

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

Military, fire fighting, rescue

- the "ideal" application because the desire to remove humans from the scene is obvious …
- much research

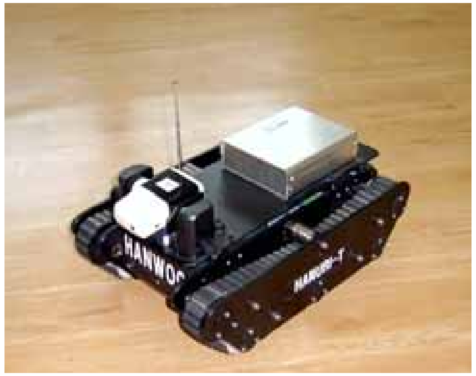


Figure B.11. Military Robot.

(Robot ethics…interesting topic)

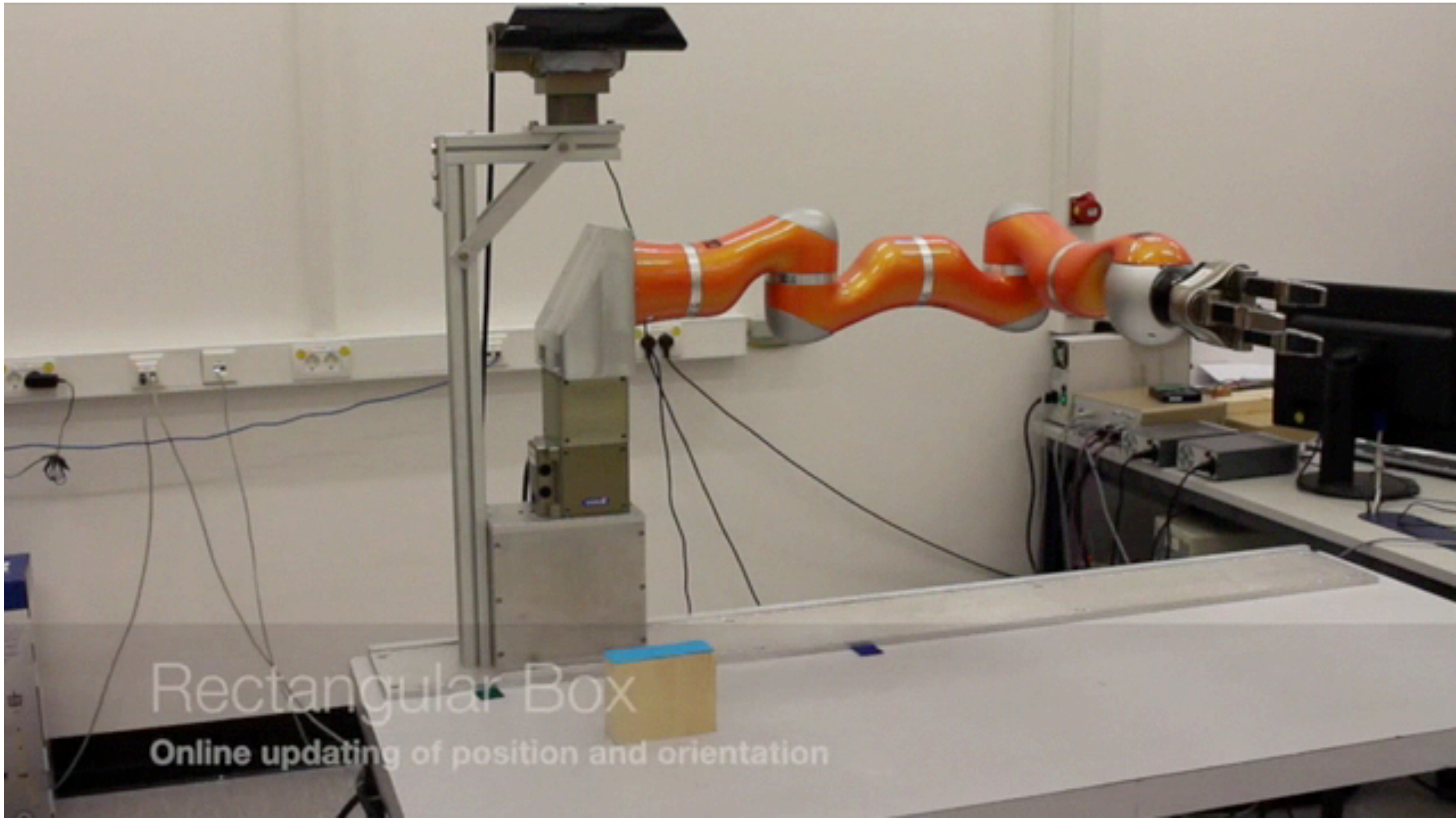
- may a military robot autonomously decide to shoot
  - …. navy vessels may already do that…
- may an autonomous car decide between avoiding a pedestrian and preventing danger for the car occupants?
- fundamental problem: off-loading decisions from user to designer …

Autonomous vehicles

- …. well, for autonomous transport…
- the best developed branch of autonomous robotics

[Amazon robotized warehouse]

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
- => fundamental challenge

Autonomous robotics as a "playground" of research

- modern engineering uses modular design that limits the range over which modules interact/interfere
- …autonomous robotics: requires close, real-time system integration

Autonomous robotics as a "playground" of research

- highly interdisciplinary field

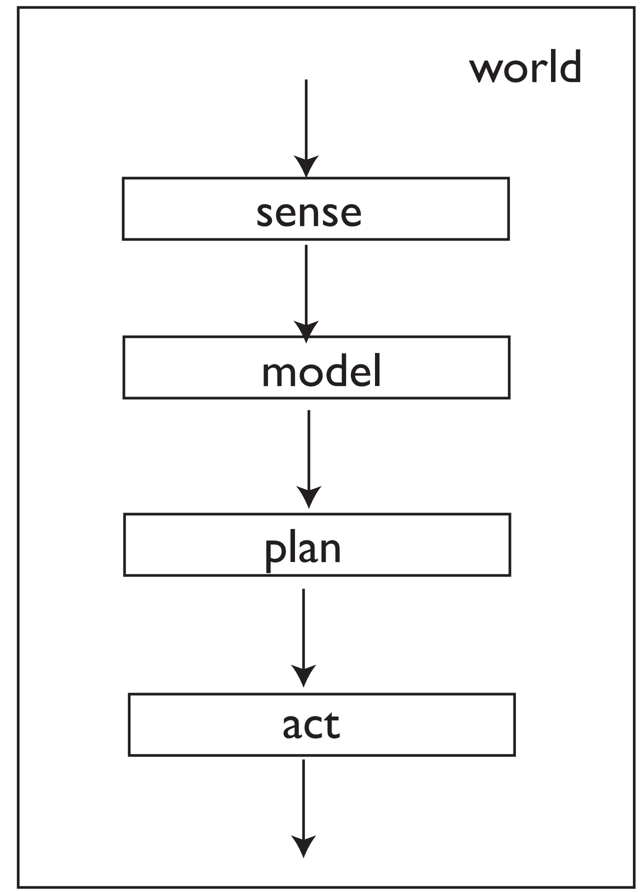
- sensing
- perception
- modeling
- AI/planning
- mechanics
- control
- compliance

- embedded computing
- communication / data security
- energetics
- user interfaces
- safety
- ethics

Overall conception of autonomous robots: architectures

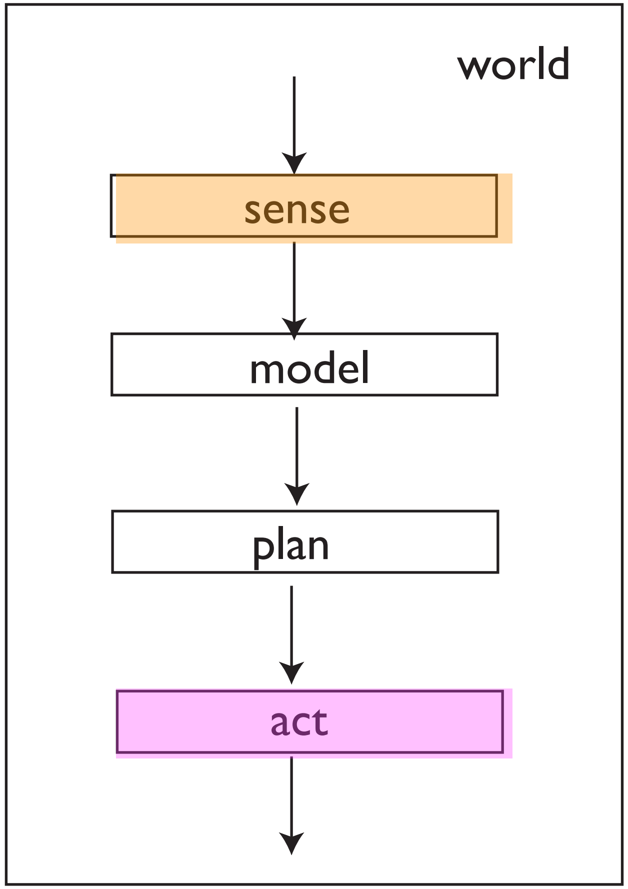
Sense-plan-act

- The classical vision dates back to the 1950's…
- separates the problem into modular functions that follow the sensory stream from sensors to motors



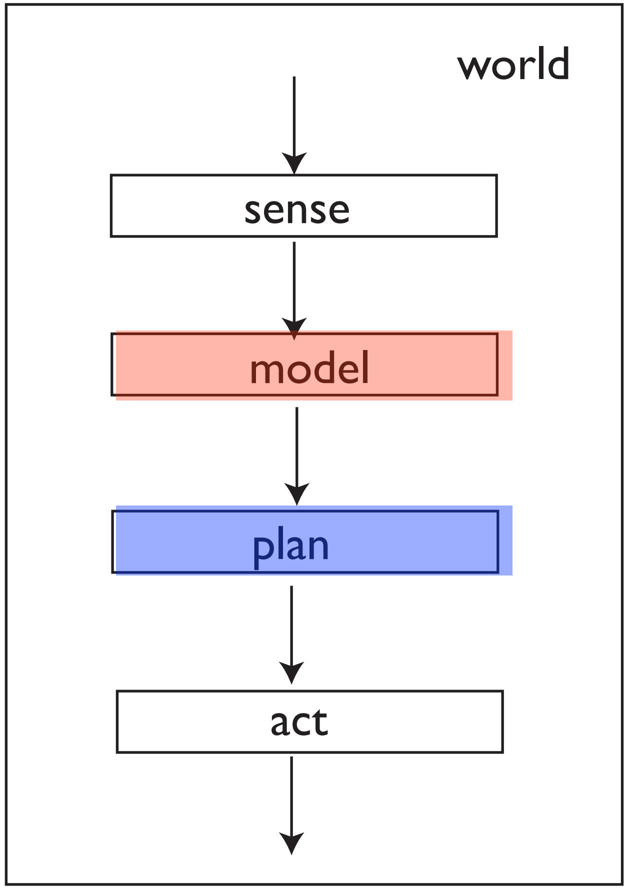
Sense-plan-act

- sensing and acting are shared with conventional robots/ engineering



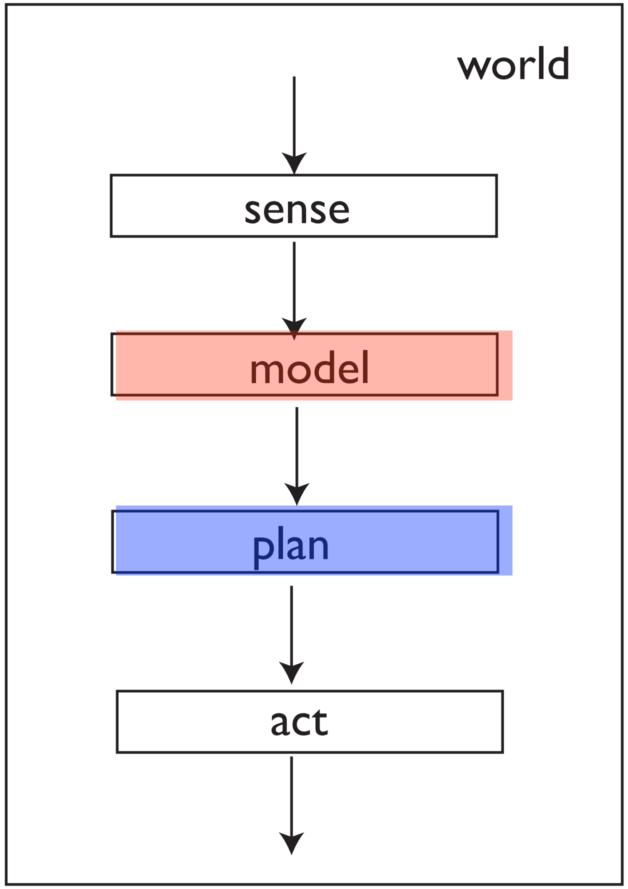
Sense-plan-act

- "intelligence" comes from two core functions
- modeling the world, which entails perception and map building
- planning action, which entails generating sequences of actions that lead to a goal



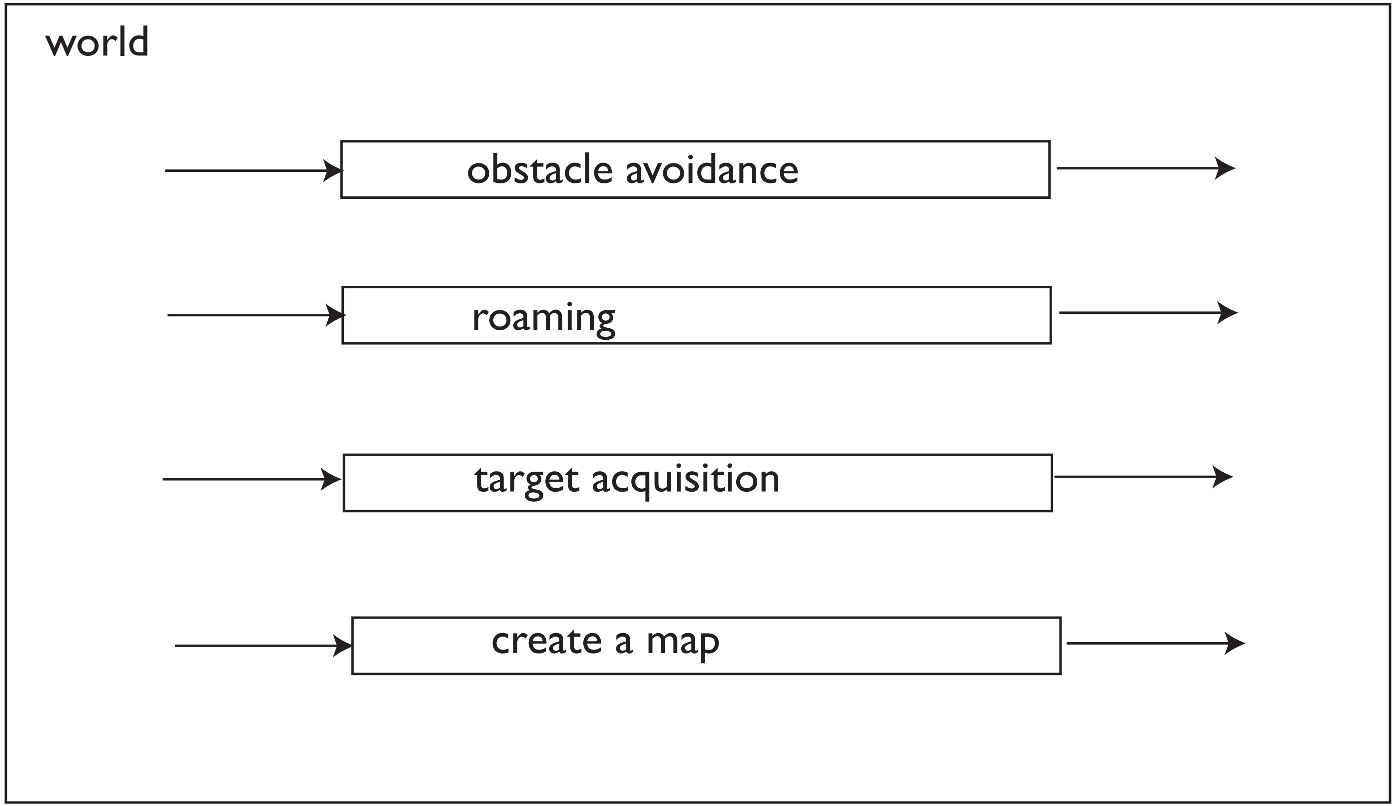
Sense-plan-act

- perception in this most general form is very difficult… => challenge of perception
- planning action separately from control difficult when interacting physically with objects/humans => challenge



Behavior-based

- minimize the difficulty of generating world models by having special purpose perception
- integrate planning and control in individual behaviors



[Brooks and others, 80’s]

Behavior-based

- quick progress toward simple, special purpose robot vehicles….

[Bicho, Schöner, 1997]

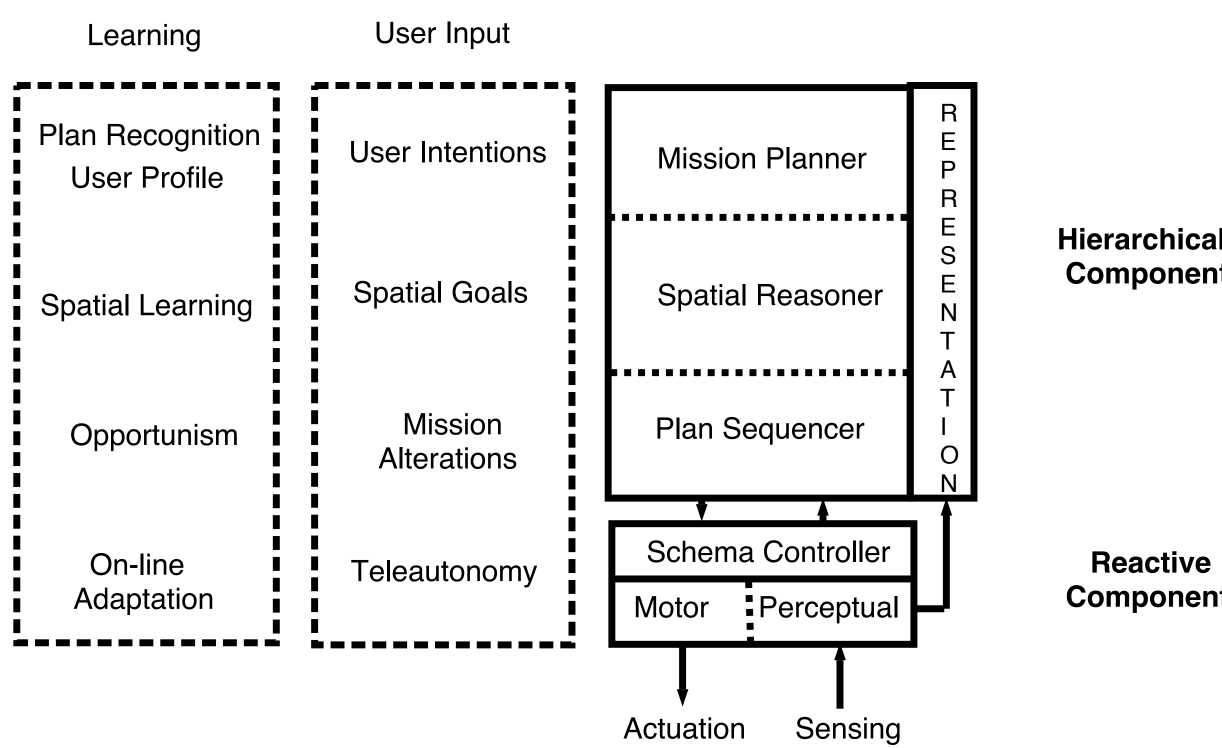
Behavior-based

- quick progress toward simple, special purpose robot vehicles….
- but limited scaling to more complex tasks that are oriented at objects, and that require world knowledge => challenge of background knowledge

[Bicho, Schöner, 1997]

Hybrid architectures

- use behavior-based ideas as a "reactive layer"
- use sense-plan-act ideas at a ``higher" level of goal-oriented planning



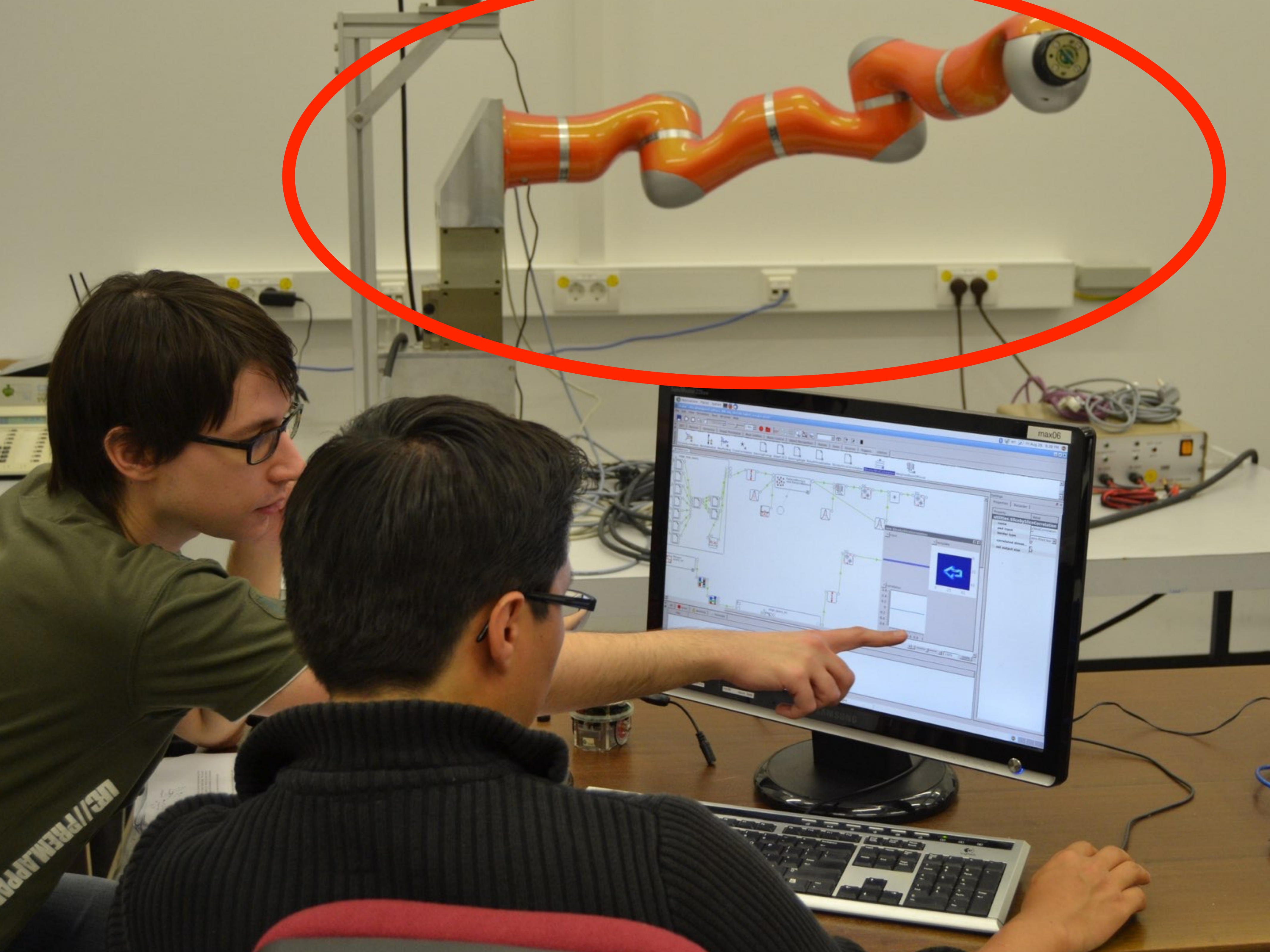
[Arkin, Balch, 1997]

4 major (remaining) challenges

- 1 perception
- 2 interacting with humans
- 3 physical interaction
- 4 background knowledge

(1) Perception

- no autonomy without perception
- perception is NOT estimating the stimulus
- it is learning about the environment and extracting meaning=that what enables action


max06

Core problems of scene/object perception

- attention: search!
- detection/classification… invariance
- estimation: pose
- continues to be a research challenge in spite of a resurgence of computer vision for robotic perception …

Core problems of perception for vehicles

- ego-position estimation (navigation)
- map-formation
- obstacle perception

Core problems of perception for vehicles

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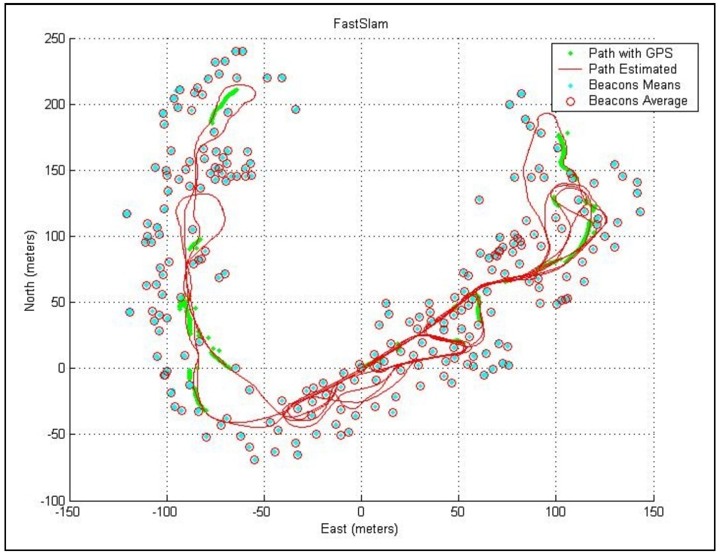
- map-formation
- obstacle perception

SLAM

SLAM

- self-localization and map formation
  - building on low-level sensors with invariant information
  - using probabilistic thinking…
  - => much progress

[Thrun, 2002]



Core problems of perception for vehicles

- ego-position estimation (navigation)
- map-formation
- obstacle perception

SLAM

depth sensing

Range sensing

- step change in depth estimation through laser range sensing

3-D laser scan
(a) Registered infrared reflectance image.
(b) Range image: closer is darker

[Springer Handbook of Robotics, Siciliano, Khatib (eds) 2016]

Core problems of perception for vehicles

- ego-position estimation (navigation)
- map-formation

SLAM

- obstacle perception

depth sensing

- => much progress in SLAM and depth sensing together with probabilistic approaches

(2) Interaction with humans

- in part also a problem of perception
  - e.g. in perceptually grounding language
- understanding language!
- joint attention
- intention perception
- linking to background knowledge

- e.g., “the red cup to the left of the green cup“ …

(3) Physical interaction

- with objects, including humans… when there is contact, force transmission..
- despite the sophistication of modern control, there is a problem at the heart of this
  - the lack of robustness of control (Doyle, 78)… deviations of model from reality generically lead to instability of control!
- limited perception: models of objects/human users are imperfect => problem

(3) Physical interaction

- example: to this day, milling is difficult for industrial robots
  - as instabilities arise as the tool moves through the material…
- milling like many other material transformation is done by specialized machines that are mechanically designed to solve the control problem

(3) Physical interaction

- one cause: separation of control and planning…
- in which control is fast/stiff, to that the plans need no updating
- but that makes high demands on perception and the modeling of objects
- and is unsafe for human workers… due to the large forces generated

Soft robotics

- inspired by human motor control…
- human actuators are compliant, and their visco-elastic properties make them relatively weak compared to the loads they handle…
- reduces demands on perception…
- but makes for challenging control problems… in which movement plans and motor control are tightly interwoven…

(4) Background knowledge

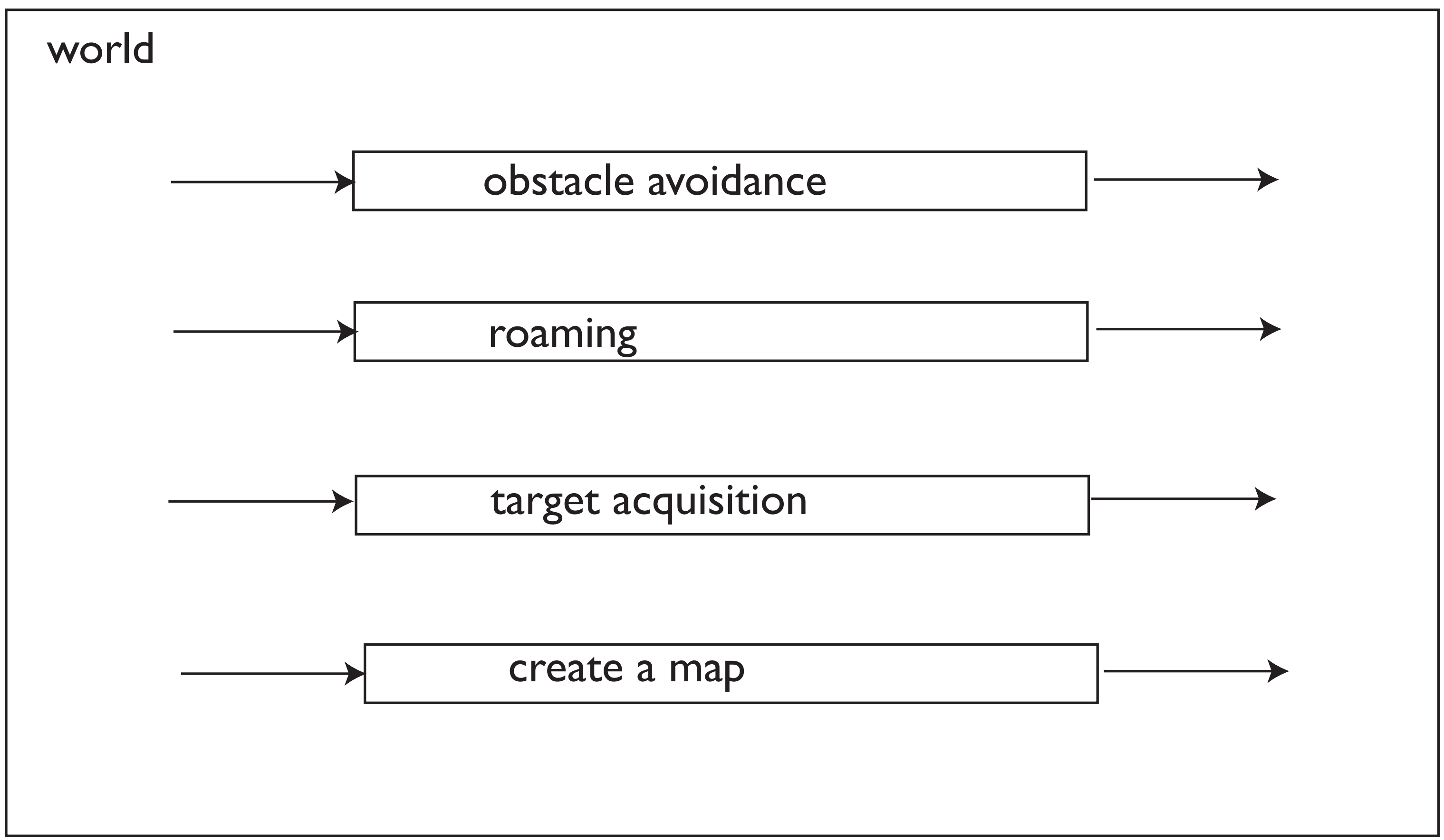
- implicit knowledge about how the world works
  - how to open a door
  - that milk is in the fridge
  - how to grasp a glas vs. a cup vs. a spoon
  - how to grasp an object to achieve a particular goal
  - to clear space before moving something to a new place…

Background knowledge

- is a core problem of classical artificial intelligence
  - knowledge representations
  - reasoning
  - action planning
  - architectures

Background knowledge

- implicit background knowledge in behavior based robotics… the background is in the individual skills and how they are connected



Background knowledge

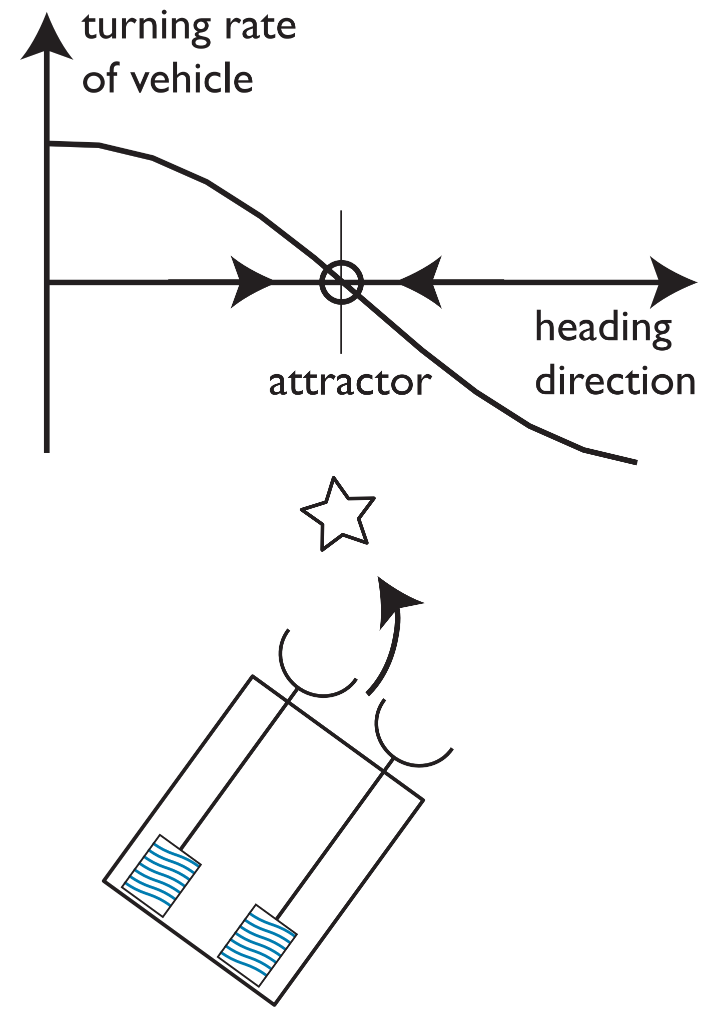
- autonomously acquiring back-ground knowledge continues to be a challenging research frontier…
  - online learning
  - continuous learning
  - autonomous learning
- reinforcement learning is a first attempt… quite limited for real world scenarios

Particular perspective of the course

- this course is NOT a standard introduction into autonomous robotics from a technical point of view
- although it provides some elements of that through
  - a review of approaches to vehicle path planning
  - a review of concepts in robotic manipulators, planning, and control

Particular perspective of the course

- the dynamical systems perspective
  - neural dynamics => WS course on Neural Dynamics
  - “behavioral dynamics” ...



Robotics is an emerging synthetic science ….
Presently missing foundations include the identification of fundamental physical limits, the development of new dynamical systems theory, and the invention of physically grounded programming languages…..

Annual Review of Control, Robotics, and Autonomous Systems

What Is Robotics? Why Do We Need It and How Can We Get It?

Daniel E. Koditschek

Department of Electrical and Systems Engineering, University of Pennsylvania, Philadelphia, Pennsylvania 19104, USA; email: kod@upenn.edu

Annu. Rev. Control Robot. Auton. Syst. 2021. 4:1–33

Particular perspective of the course

- autonomous robotics as a tool for the theory of cognitive systems
- to test neural models of cognition and behavior…
- => integrative framework of dynamical systems

Syllabus

- dynamical systems tutorial
- vehicles
  - attractor dynamics approach to motion planning
  - other approaches to motion planning
  - analogy to navigation in humans and animals
- robot arms
  - kinematics, degree of freedom problem
  - dynamics, control
  - timing
  - movement generation with muscles

Embedding in the field

- the Springer Handbook of Robotics, Siciliano, Khatib (eds) 2016
- ~2200 pages!

Foundations… “classical”robotics (not autonomous robotics)

Part A Robotics Foundations

[Springer Handbook of Robotics, Siciliano, Khatib (eds) 2016]

Foundations… "classical" robotics (not autonomous robotics)

[Springer Handbook of Robotics, Siciliano, Khatib (eds) 2016]

Foundations… “classical”robotics (not autonomous robotics)

[Springer Handbook of Robotics, Siciliano, Khatib (eds) 2016]

Foundations… autonomous robotics

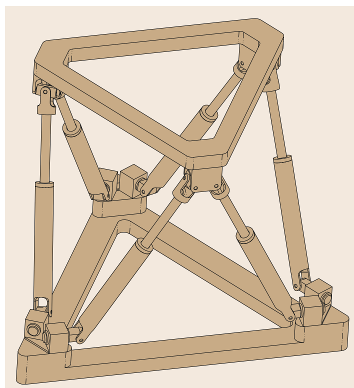
[Springer Handbook of Robotics, Siciliano, Khatib (eds) 2016]

Design

Part B Design

[Springer Handbook of Robotics, Siciliano, Khatib (eds) 2016]

Design



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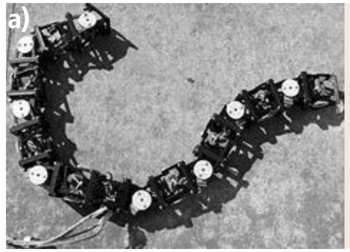
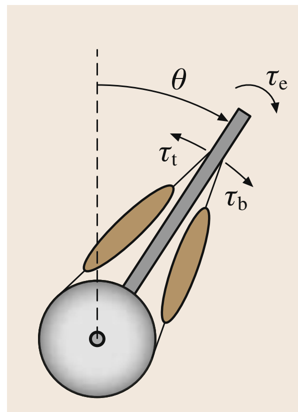
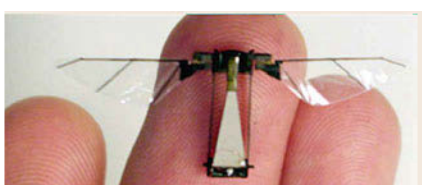
Design







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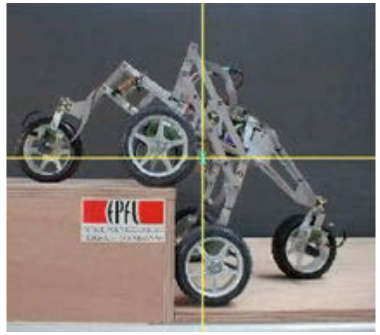
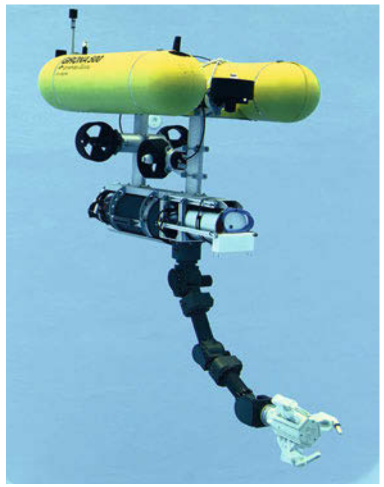
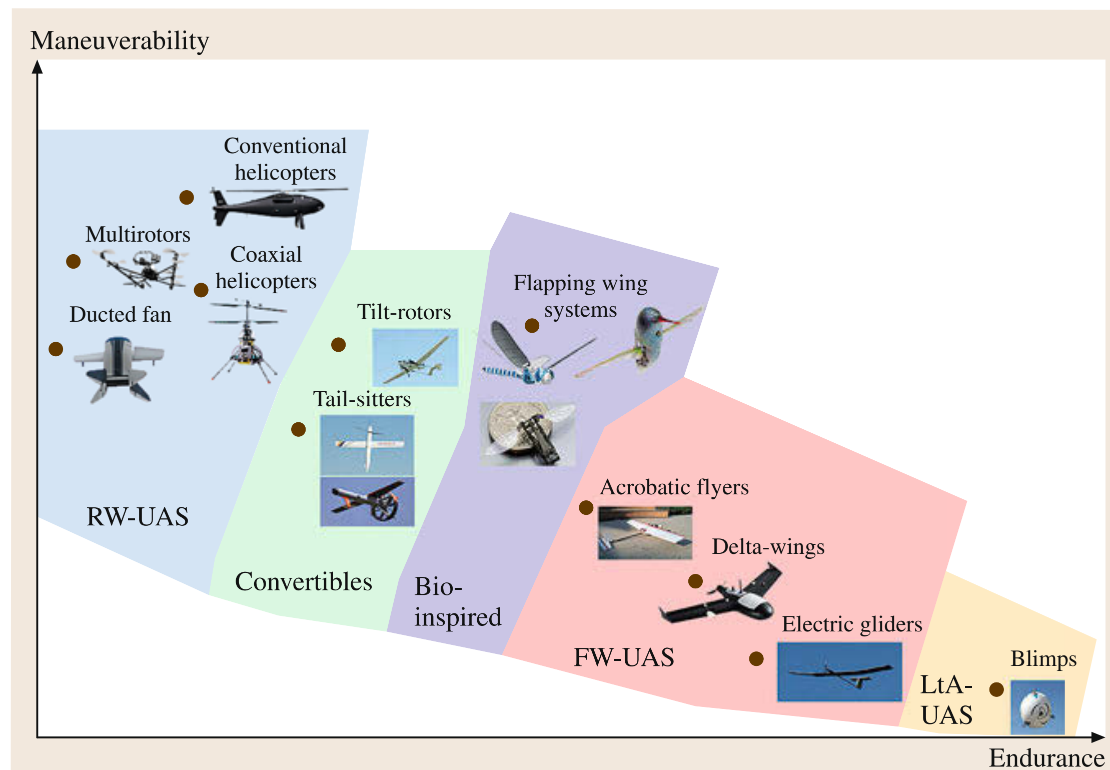
Design

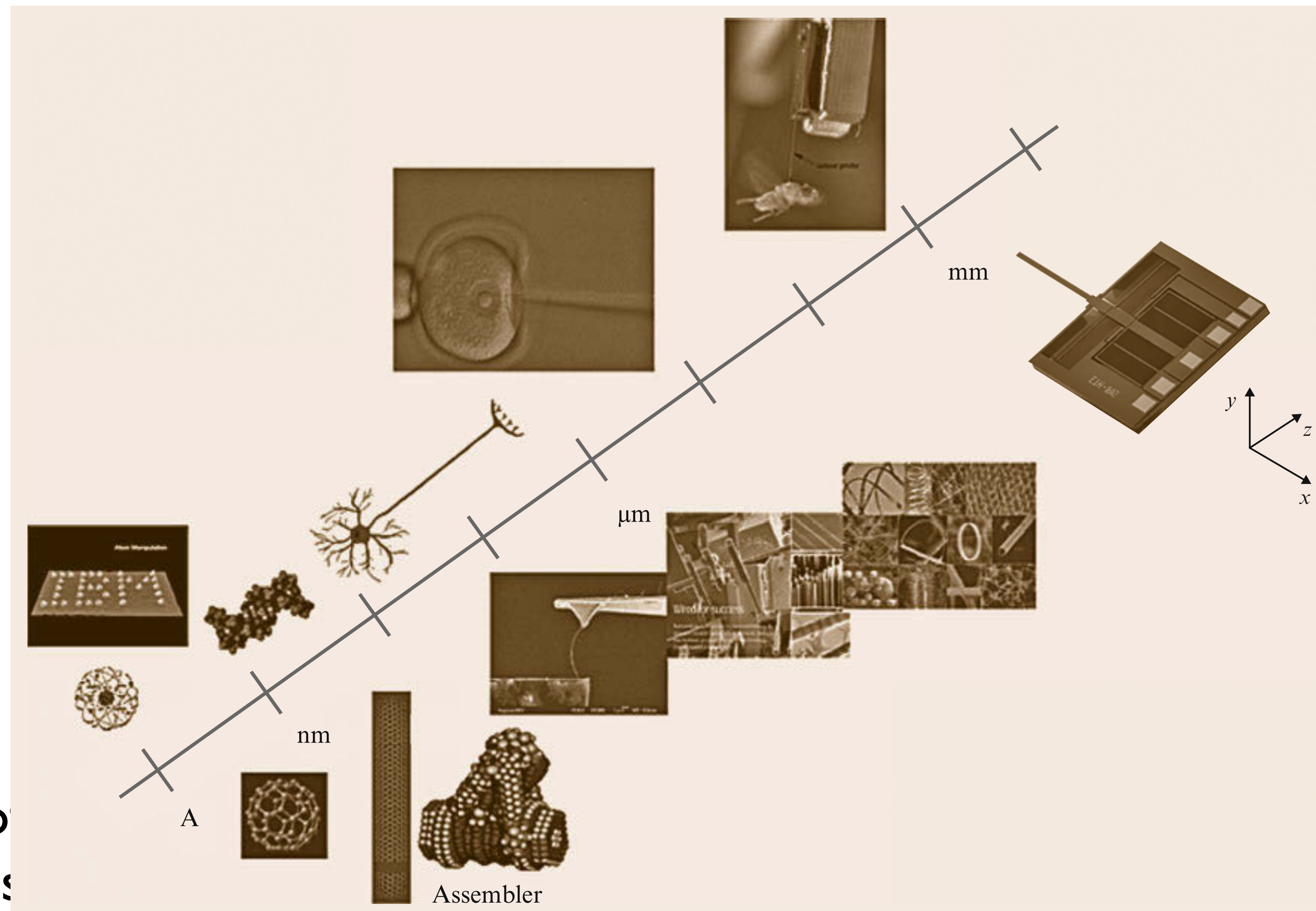






[Springer Handbook of Robotics, Siciliano, Khatib (eds) 2016]

Robot designs



[Springer Handbook o
Siciliano, Khatib (eds

Sensing and perception

Part C Sensing and Perception

Manipulation and interfaces

Part D Manipulation and Interfaces

Moving in the environment

Part E Moving in the Environment

Moving in the environment

Robots at work

Part F Robots at Work

Robots at work

Robots and humans

Part G Robots and Humans

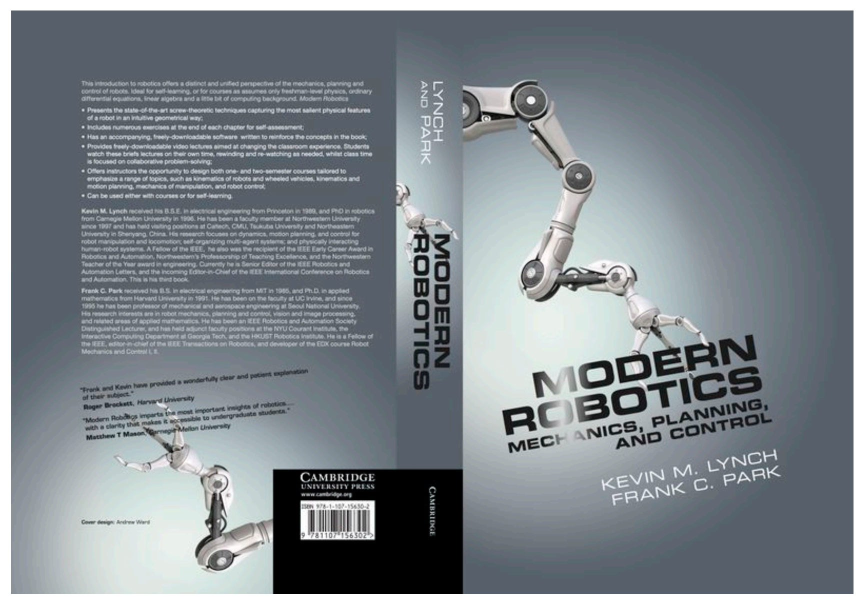
Robots and humans

A text book

- quite accessible.. and preprint available online

MODERN ROBOTICS

MECHANICS, PLANNING, AND CONTROI



Kevin M. Lynch and Frank C. Park