Learning Robotics

... On the shoulders of giants...

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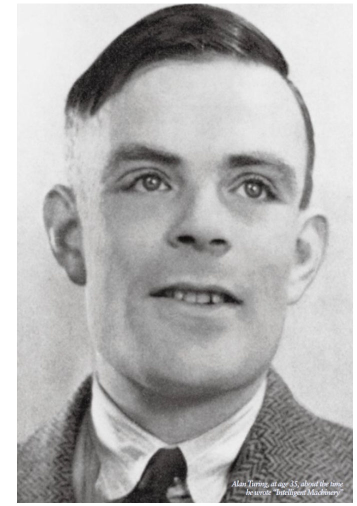
Intelligent machines

- Alan Turing 1948 (1970 published) wrote the Paper ‚intelligent machinery'
  - In this paper he refutes 5 thesis ‚why AI can't work"
  - He creates the foundations for robotics or better ‚embodied robotics'
    - cite: „...it is possible to make machines that imitate any small part of a man...'
  - He sees in these systems the key to study artificial intelligence
    - They are capable to interakt with the environment and to ‚learn from the interaction'
    - cite: „...let it find out things by itself and roam the country side...'
  - He concludes that these robots –with the technology of that time– would be big, heavy and simply not practical
    - cite '...all together too slow and impractical...'
    - cite' „... pose a substantial threat to the local population...'



Intelligent Machinery

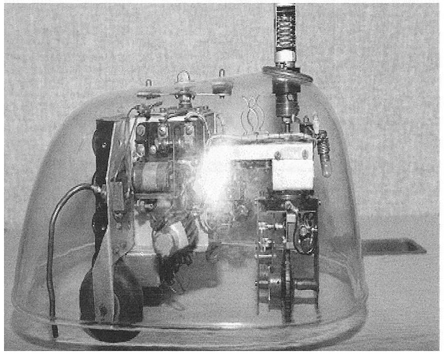
A. M. Turing
[1912—1954]

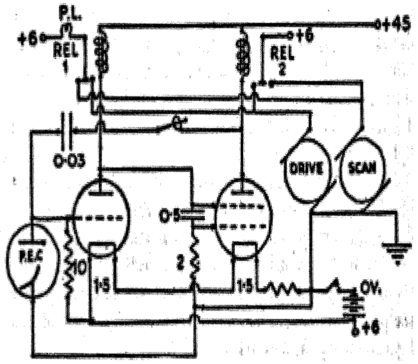
Abstract

The possible ways in which machinery might be made to show intelligent behaviour are discussed. The analogy with the human brain is used as a guiding principle. It is pointed out that the potentialities of the human intelligence can only be realized if suitable education is provided. The investigation mainly centres round an analogous teaching process applied to machines. The idea of an unorganized machine is defined, and it is suggested that the infant human cortex is of this nature. Simple examples of such machines are given, and their education by means of rewards and punishments is discussed. In one case the education process is carried through until the organization is similar to that of an ACE.

Birth of AI

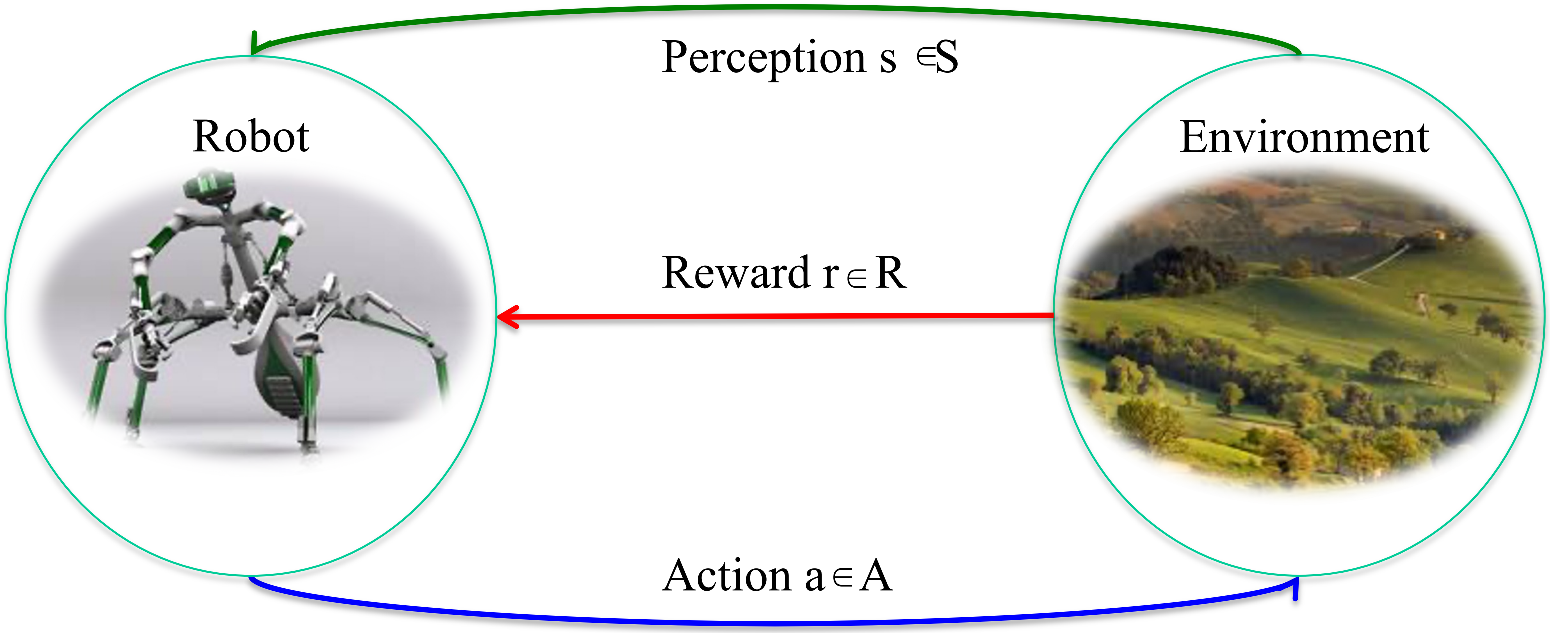
- Because of the technical deficitis of the time (1948) A. Turing proposes 5 areas of research for AI:
    1. ‚Game playing' (chess, Go, ...)
    2. Natural language
    3. Translation
    4. Cryptology
    5. Mathematics (Logic, Reasoning,...)





- He designed the Roadmap for AI Research
    - Items1, 3 and 5 are key areas of AI still today
- Robotic technology in 1948
    - Grey Walters Turtle
        - EEG Reseracher (Theta and Delta waves)
        - Turtle Robot
    - The Ratio Club (Dining Club)
        - British cybernetic school

The Robotics problem...



Function that maps Perceptions to Actions : $[f: S \rightarrow A]$

Optimizing the long term Reward : $E\,[r(t) + \Upsilon^{1} r(t+1) + \Upsilon^{2} r(t+2) + \Upsilon^{3} r(t+3) + \ldots] = Q(s,a)$

Finding a Policy to always do the right thing : $P^{*} = \text{argmax } Q(s^{t},a^{t}),\ t=1,\ldots,\infty$

Long Term Autonomy

1. ***Finite-horizon*** $E(\sum_{t=0}^{h} r^{t})$

- At every step t the agent optimizes the expected reward for the next h steps
- H limits how far the agent can look into the future

1. ***Infinite horizon*** $E(\sum_{t=0}^{\infty} g^{t} r_t)$

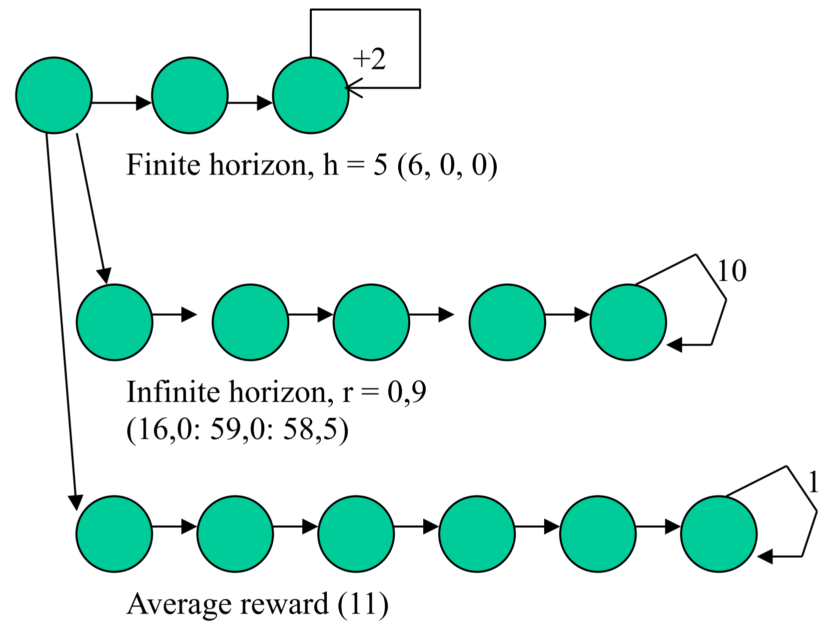
- Long Term reward is in focus
- Reward in the future will be weighted geometrically less ($0 \leq g \leq 1$)

1. ***Average-reward***

$$\frac{\lim}{h \to \infty} E(\frac{1}{h}\sum_{t=0}^{h} r_t)$$

- Optimise the long term average reward
- It is difficult to distiguis two policies: one that gains a lot of reward initially and one that does not but gains good reward on average.

Modells of optimal behaviour



Implementing the ‚Policy‘

Richard Sutton

Initialize $Q(s,a)$ arbitrarily

Repeat (for each episode):

  Initialize s

  Repeat (for each step of episode):

    Choose a from s using policy derived from Q (e.g. ε-greedy)

    Take action a, observe r, s'

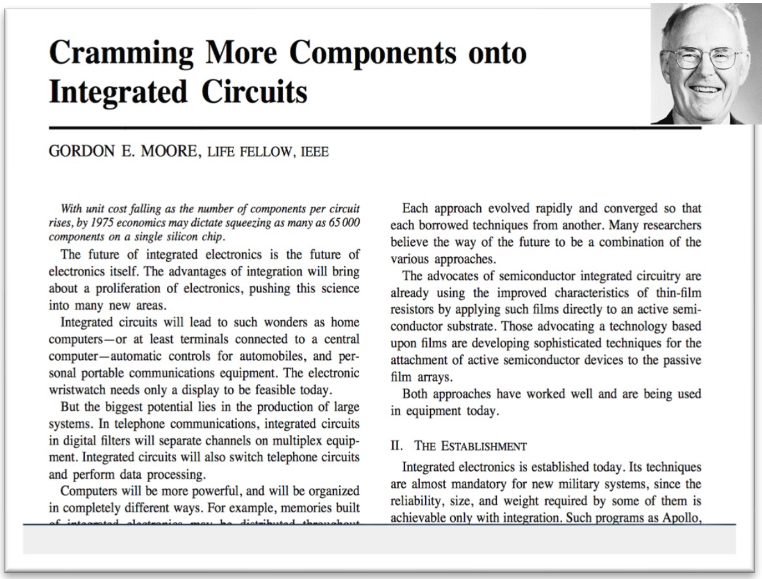
    $$Q(s,a) := Q(s,a) + a\,[r + \underbrace{\gamma \max_{a'} Q(s',a') - Q(s,a)]}_{\textbf{Here is the long term autonomy part...}}$$

    $s := s'$;

Until s is terminal

IT enabled Robotics

- Gordon Moore 1965 wrote a paper in the journal ‚Electronics‘
  - ‚He forsees in this 3-pager the exponential growth of performance of IT Technology (IC‘s)
    - cite: ‚...integrated circuits will lead to home computers, ...automatic automobile control...‘
    - cite: ‚...even personal portable computation equipment becomes possible...‘
  - The exponential growth of performance of systems in various ares enabled the real robotics:
    - IT Systems (embedded computation, digital radio, etc...)
    - Sensor systems: Cameras, Force and haptic – Sensors
    - Battery technology



Cramming More Components onto Integrated Circuits

GORDON E. MOORE, LIFE FELLOW, IEEE

With unit cost falling as the number of components per circuit rises, by 1975 economics may dictate squeezing as many as 65 000 components on a single silicon chip.

The future of integrated electronics is the future of electronics itself. The advantages of integration will bring about a proliferation of electronics, pushing this science into many new areas.

Integrated circuits will lead to such wonders as home computers—or at least terminals connected to a central computer—automatic controls for automobiles, and personal portable communications equipment. The electronic wristwatch needs only a display to be feasible today.

But the biggest potential lies in the production of large systems. In telephone communications, integrated circuits in digital filters will separate channels on multiplex equipment. Integrated circuits will also switch telephone circuits and perform data processing.

Computers will be more powerful, and will be organized in completely different ways. For example, memories built

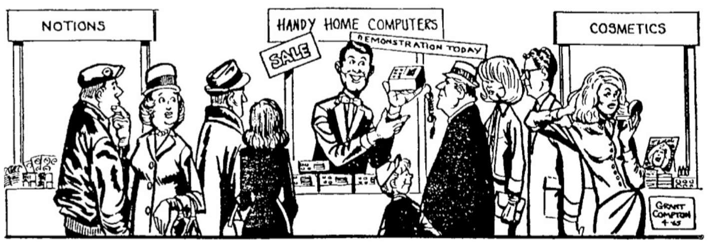
Each approach evolved rapidly and converged so that each borrowed techniques from another. Many researchers believe the way of the future to be a combination of the various approaches.

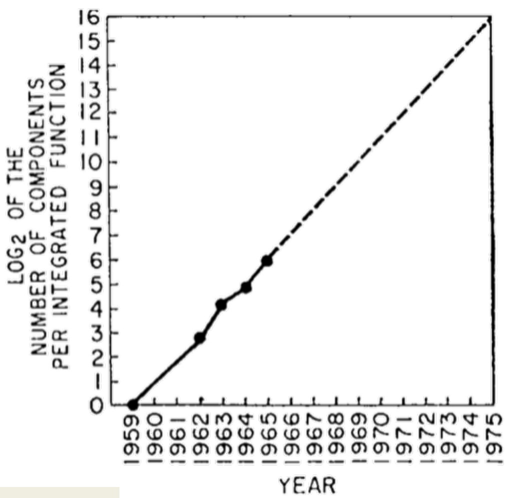
The advocates of semiconductor integrated circuitry are already using the improved characteristics of thin-film resistors by applying such films directly to an active semiconductor substrate. Those advocating a technology based upon films are developing sophisticated techniques for the attachment of active semiconductor devices to the passive film arrays.

Both approaches have worked well and are being used in equipment today.

II. THE ESTABLISHMENT

Integrated electronics is established today. Its techniques are almost mandatory for new military systems, since the reliability, size, and weight required by some of them is achievable only with integration. Such programs as Apollo,





ROBOT DRIVES:
THE ACTUATOR AS AN ELECTROMECHANICAL SUB-SYSTEM

DFKI-RIC Actuator

- Is now used in many systems
- Identical basic principles

- Three main components

- Power Electronics
- FPGA-based Control
- Communication

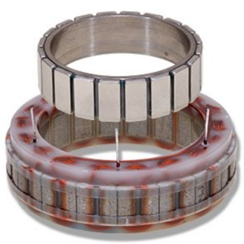
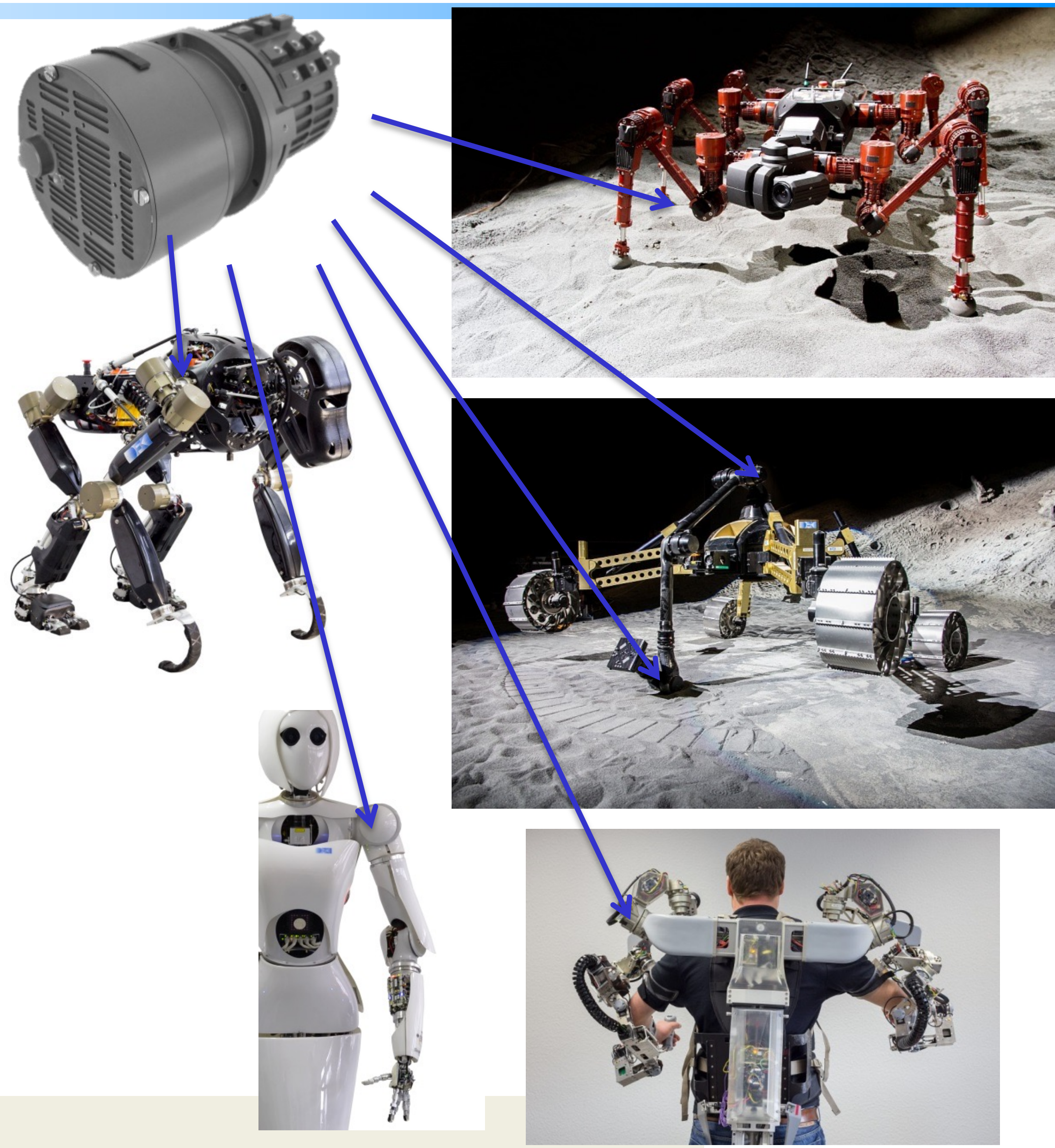


Image credit: tq-systems

- Brushless DC Motor

Image credit: Harmonic Drive AG

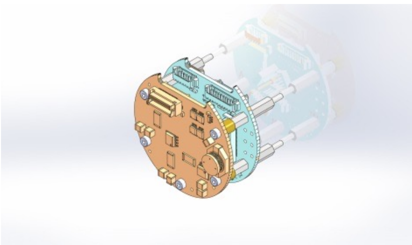
- Strain Wave Gear (Harmonic Drive)



Modular Actuator Concept

Elektronic + Motor + Gears + Options

Elektronic



„BLDC-Stack“
- Power Electronics
- Local control
  - Speed
  - Position
  - Curent
- Communication

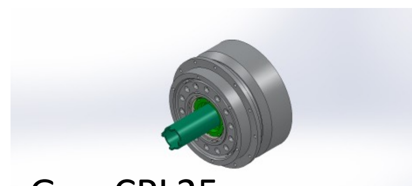
Motor

Motor-Modul ILM50
- 0,50 Nm
- 3500 rpm

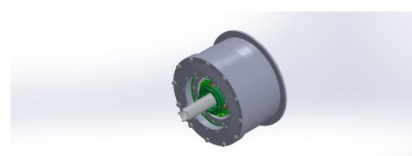
Motor-Modul ILM70
- 0,74 Nm
- 3500 rpm

Gears

Gear CPL17
- 1:30, 1:50, 1:80, 1:100, 1:120



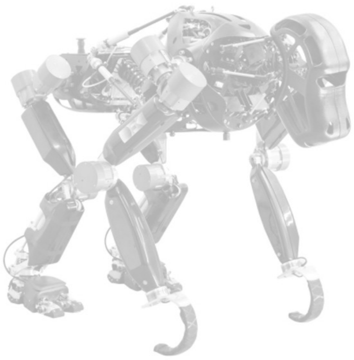
GearCPL25
- 1:30, 1:50, 1:80, 1:100, 1:120, 1:160



HighTorque Gear
- 1:3000

Options

Linear-Aktuator Kit



INTELLIGENT STRUCTURES FOR MOBILE ROBOTS

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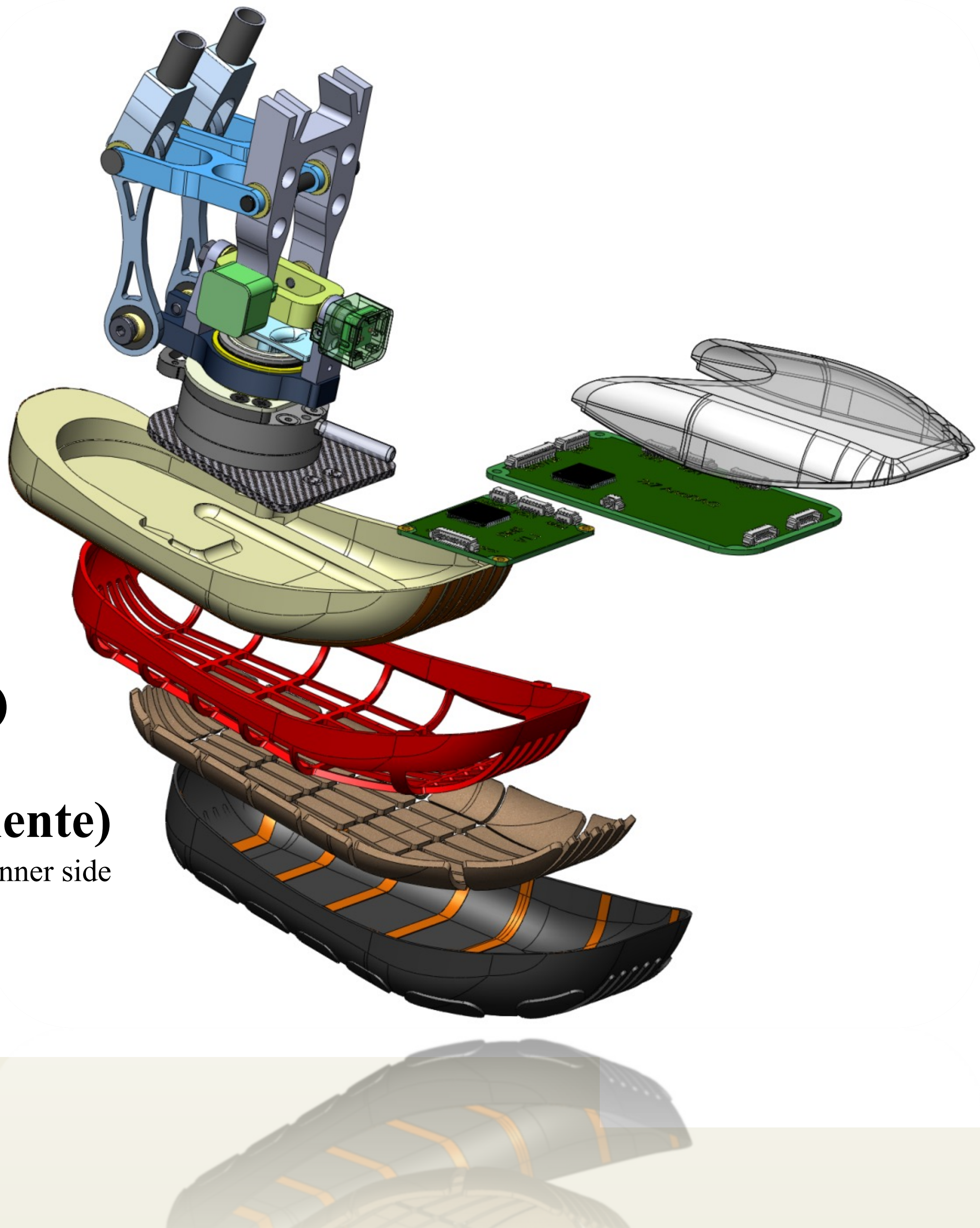
Intelligent structures

Base (Rapid Prototyping)
With electrodes on the lower side

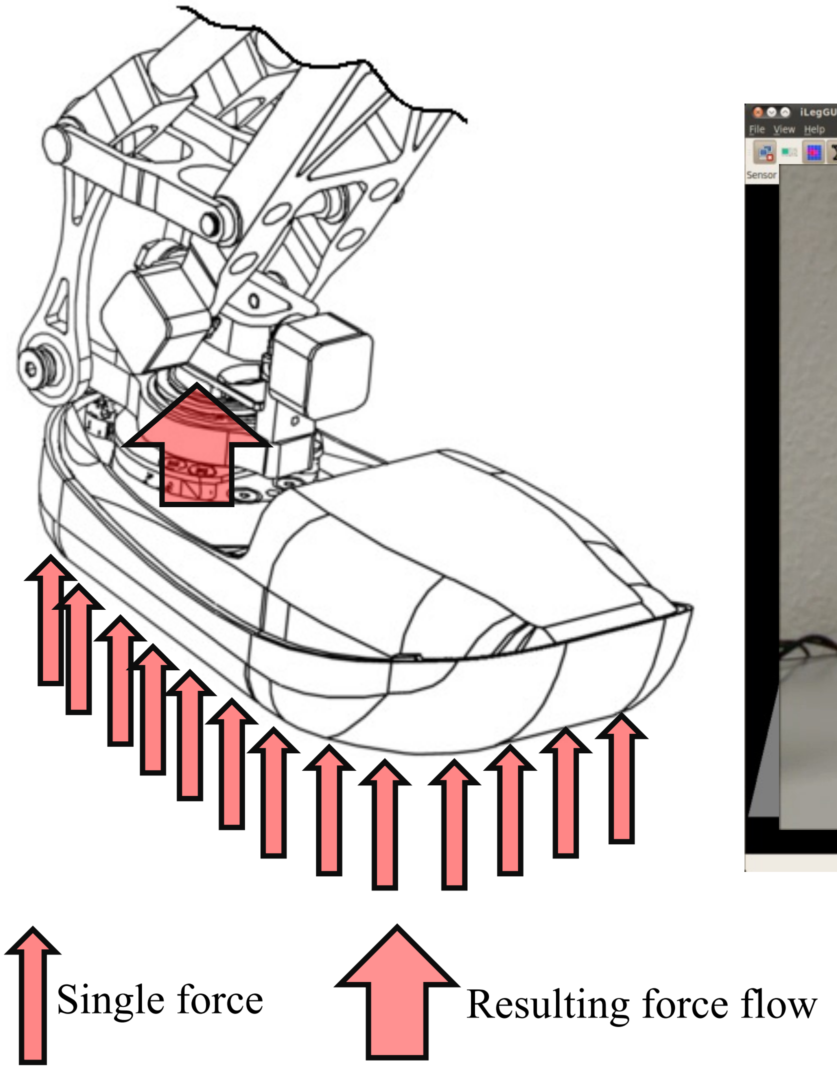
Segmentiation grid (RP)

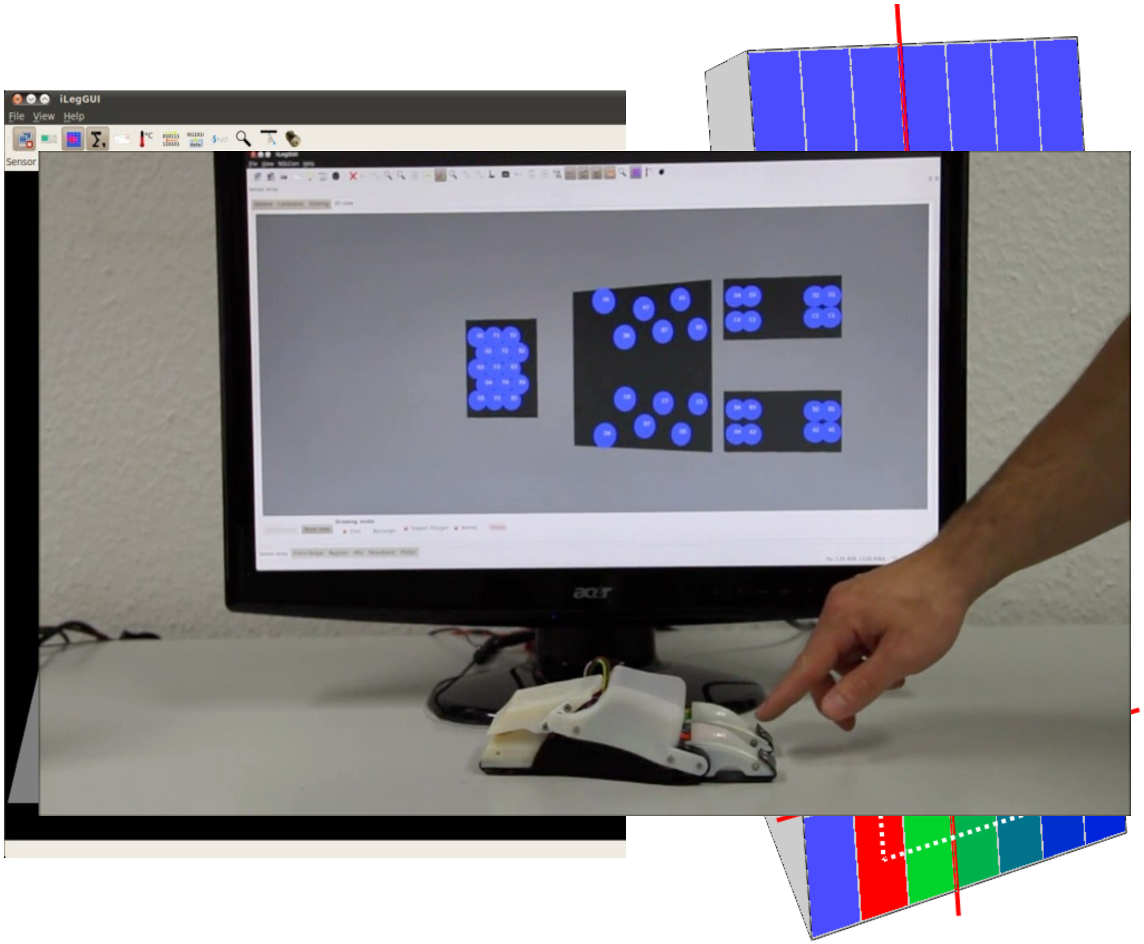
Sensoric material (Zoflex)

Rubber sole (sewed Segmente)
with electriodes on inner side

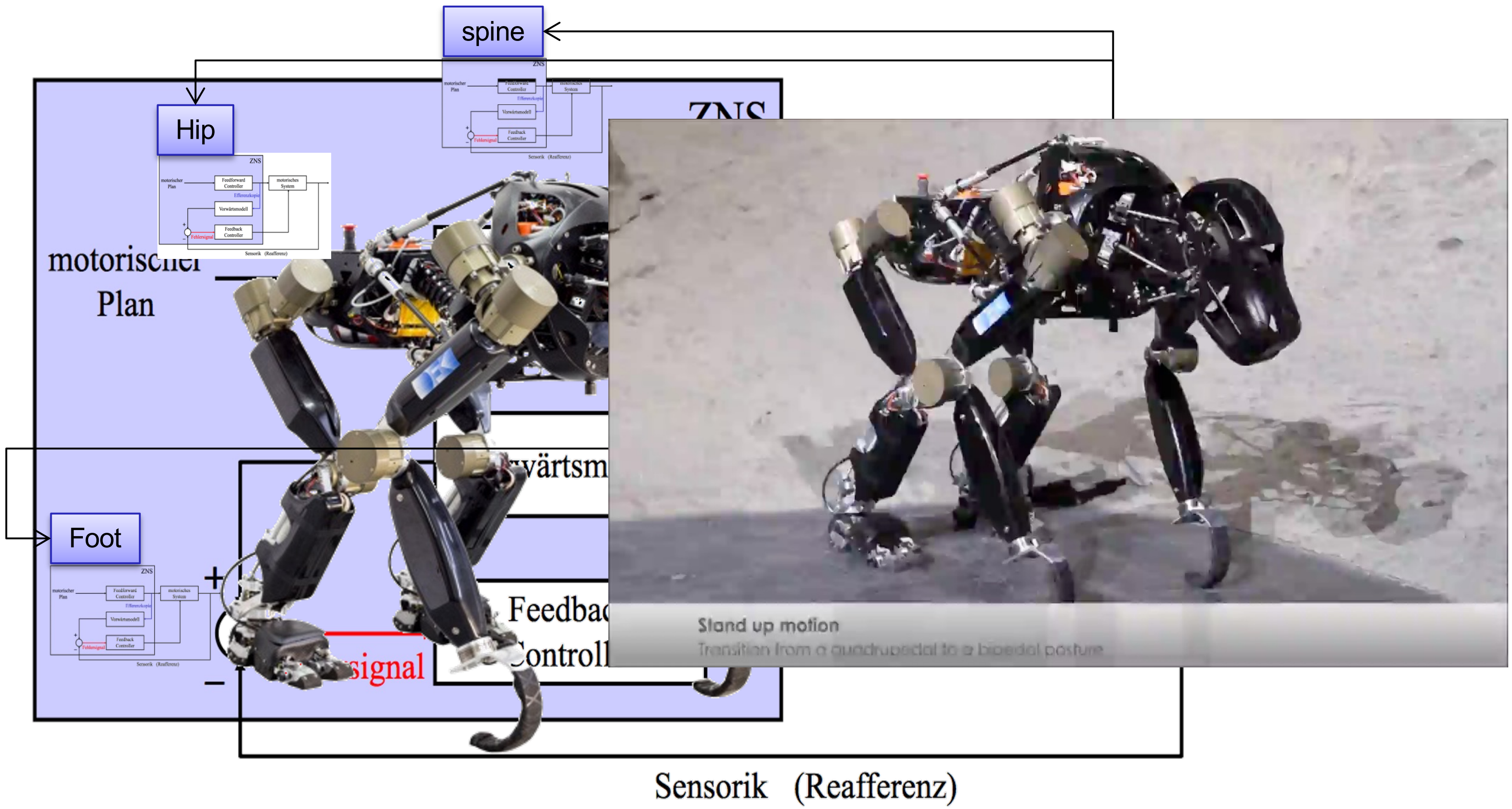


Sensor-Concept





Local Control: Efference copy



Kuehn, D., Schilling, M., Stark, T., Zenzes, M., and Kirchner, F.
System Design and Field Testing of the Hominid Robot Charlie. Submitted to Journal of Field Robotics 2014.

EMBODIED LOCALISATION AND MAP MAKING (WHY ALL THE EFFORT IS WORTH IT)

Probabilistische Navigation

Robot Navigation

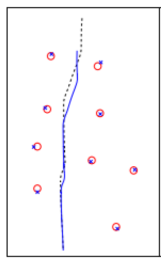
Lokalisation
Mapping
Control

SLAM

Bayes'sche methods

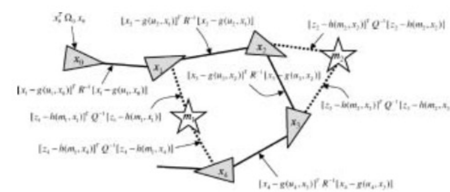
Rao-Blackwellized Partikel Filter

RBPF (Doucet, Murphy)
FastSLAM (Montemerlo)

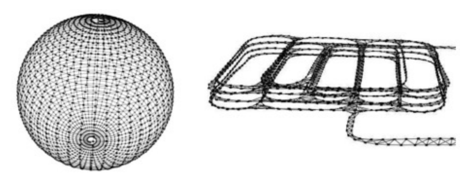


GMapper (Grisetti)

Constraint Graph Optimization



GraphSLAM (Thrun)



g²o (Kuemmerle)

Used intensively
but only optical sensors…

Embodied data

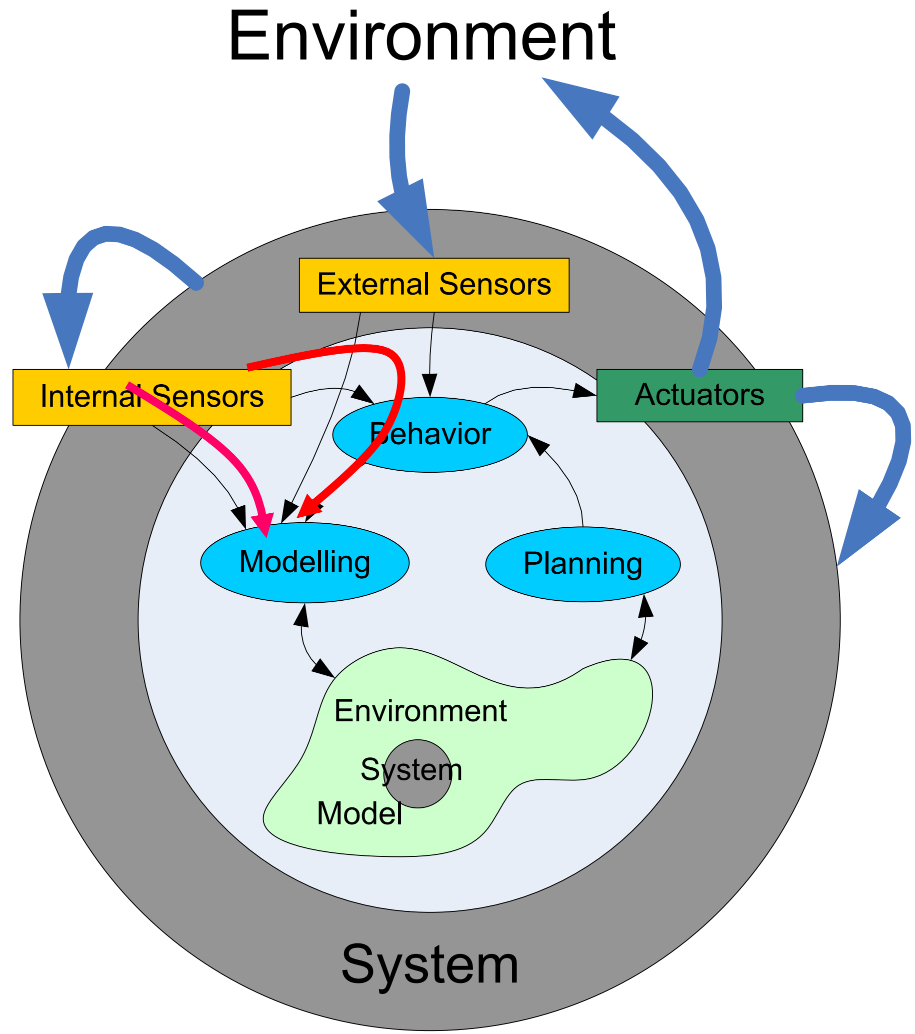
Sensor information
coming direct from the robot

Two categories:

Direct and indirect

Is used very seldom in robotics???

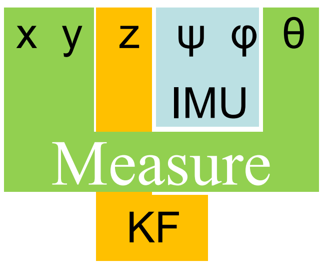
Improves environment model: precision, efficiency and System-relevance



‘Embodied Localisation’

3D Maps

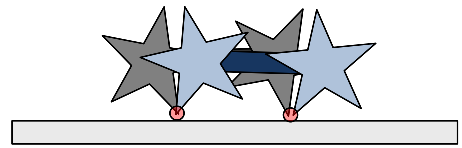
Uncertainty



x , y : GPS
z : KF prediction
ψ φ : Roll, Pitch fromIMU
Θ : headingfromGPS,IMU

Odometry model

embodied-embodied



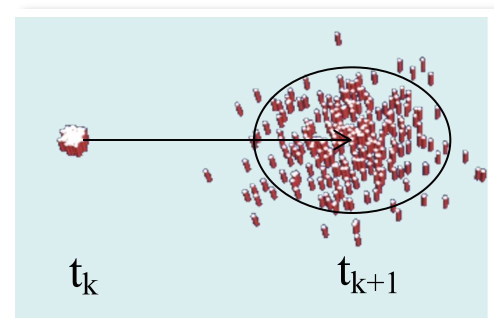
Loacalisation improvement thru odometrie modell

Sensoren

IMU

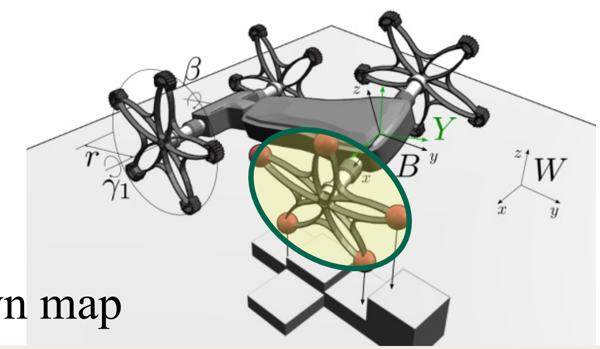
Encoders

Particle filter



Contact model

visual-embodied



Known map

Improvement of localisation thru contact model

LEARNING ROBOTS

Reinforcement Learning

Artificial Intelligence

Control Theory and Operations Research

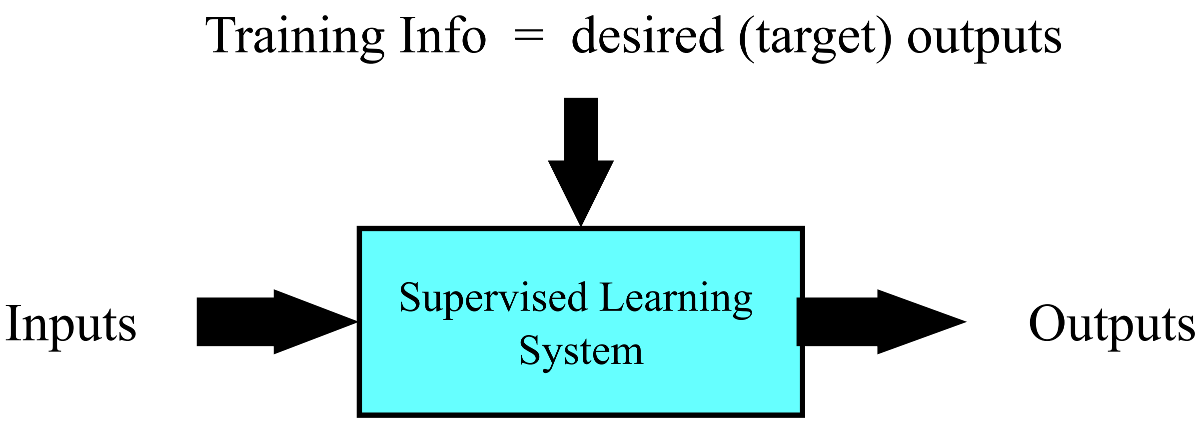
Psychology

Reinforcement Learning (RL)

Neuroscience

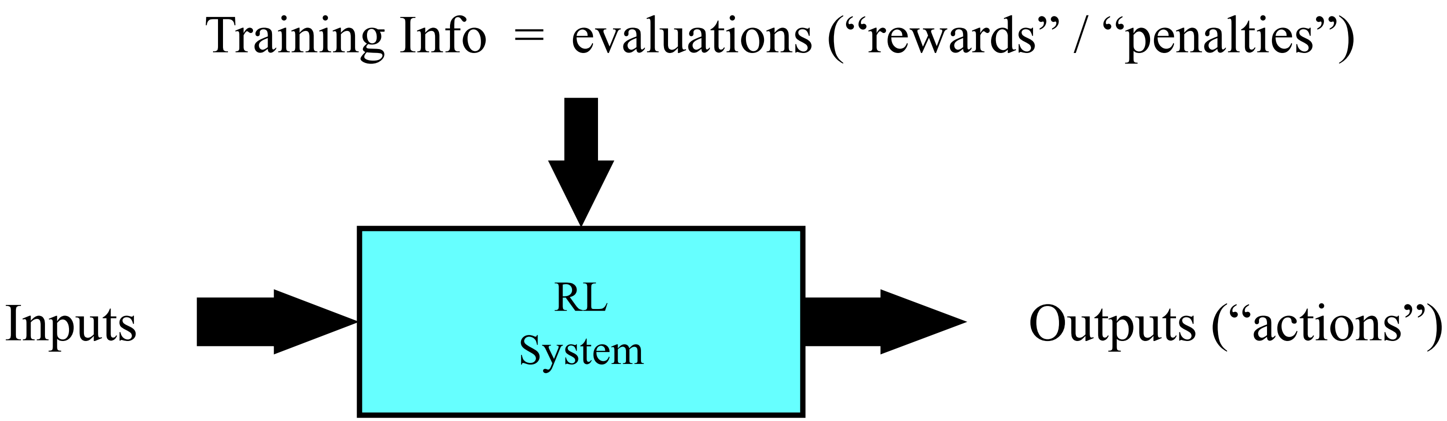
Artificial Neural Networks

Supervised Learning



Error = (target output – actual output)

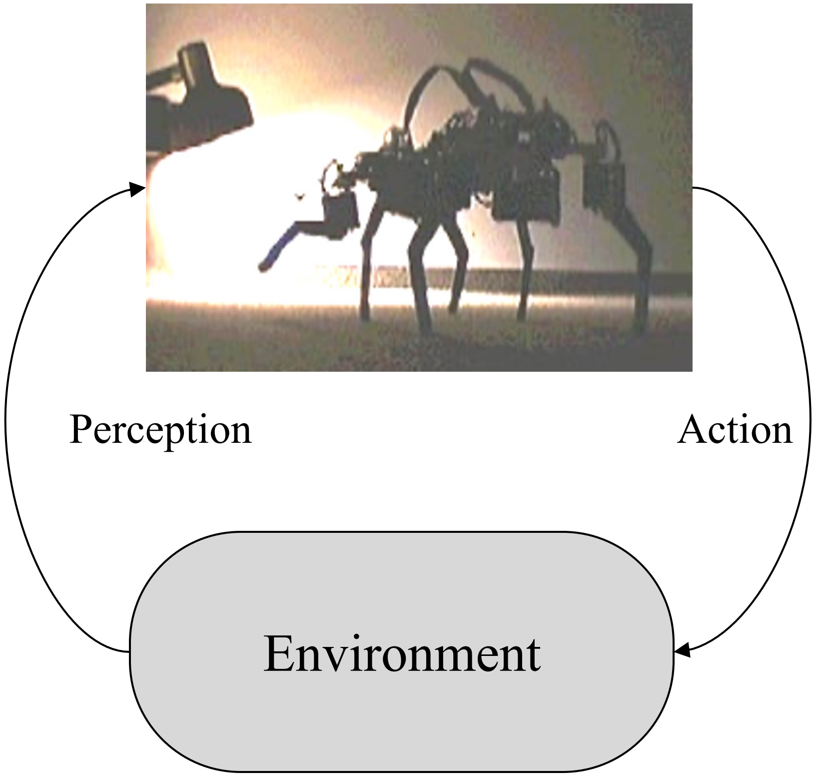
Reinforcement Learning



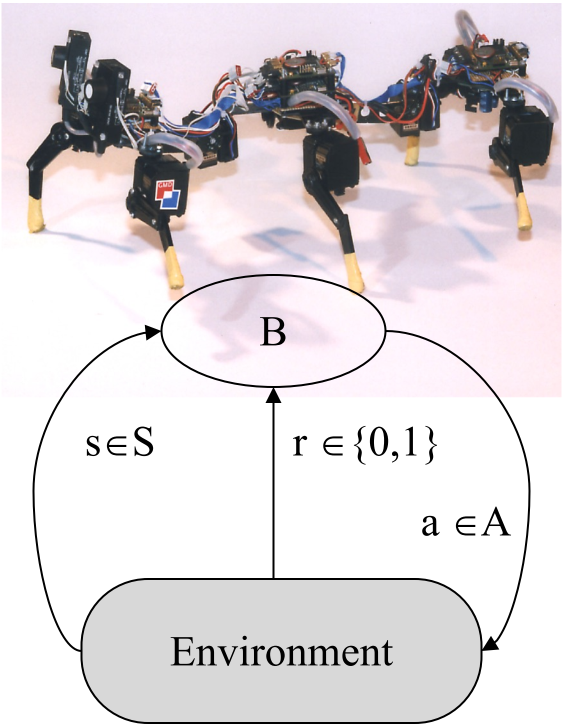
Objective: get as much reward as possible

Learning on Robots

- Robot learns from interaction with the environment
- Acquires skills to achieve goals
- Little or no prior knowledge is required
- Knowledge can be incorporated easily

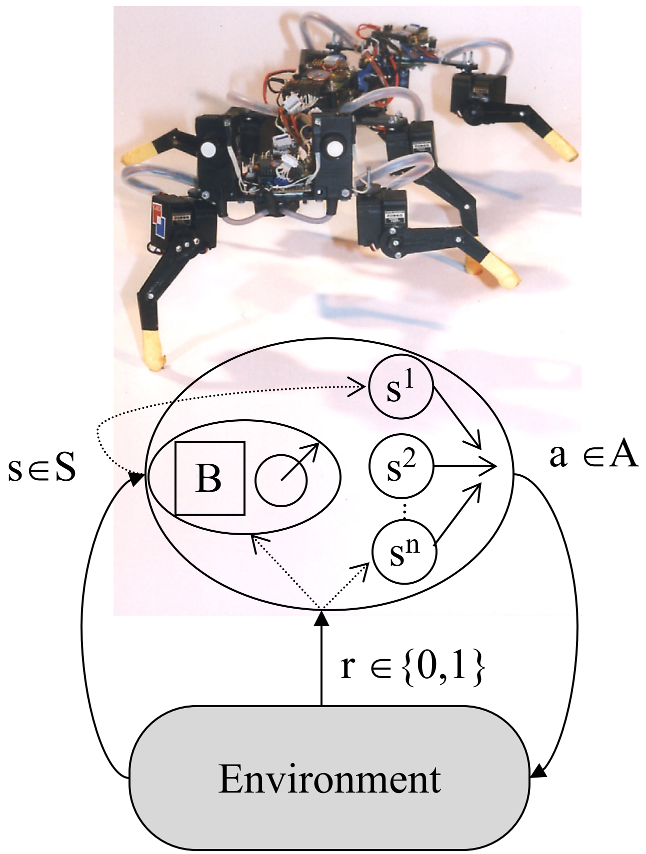


- a discrete set of states **S**
- a discrete set of actions **A**
- a set of reinforcement functions; typically {0,1}
- Learning objective: behaviour, **B: S→ A**



Learning skills

- a piece of knowledge
- solves a given problem (task)
- is part of the solution to a larger problem (task)
- can be reused in many different large problems



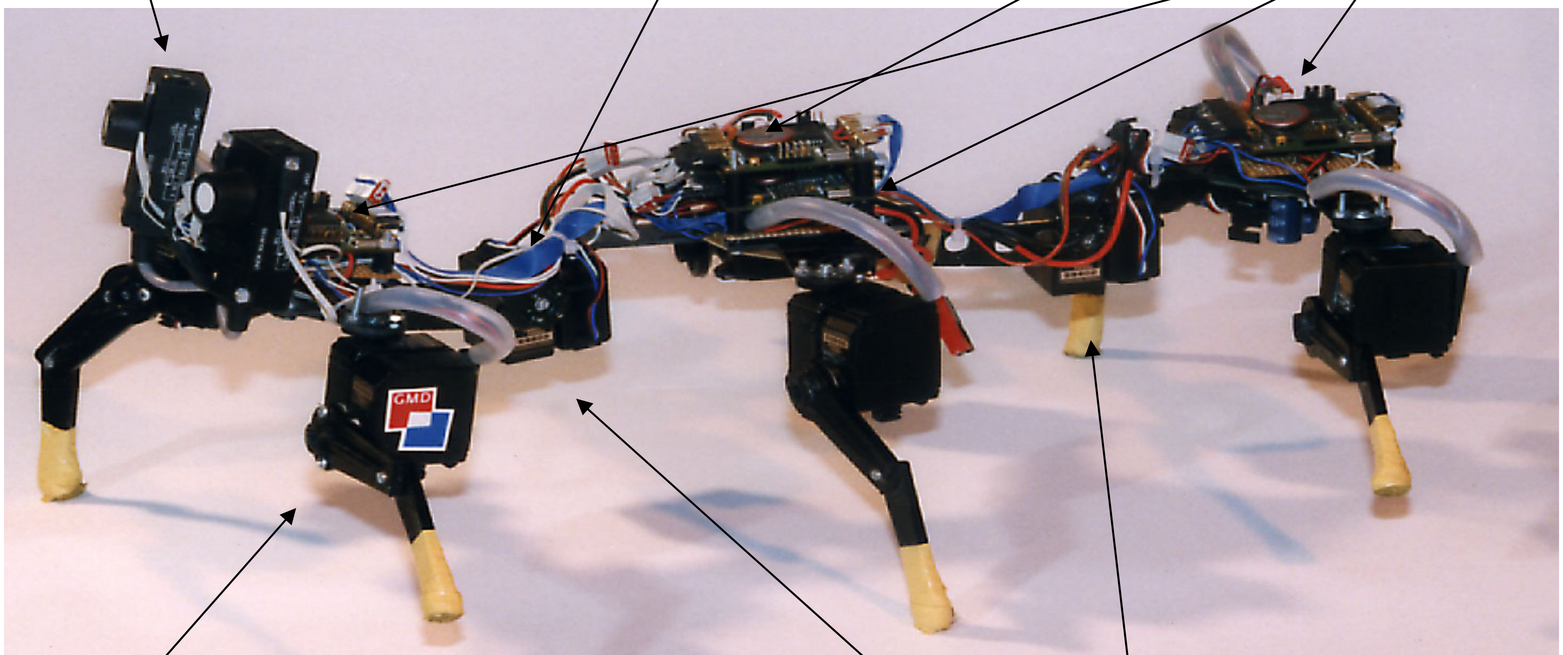
Sir Arthur

Ultra sound distance and 4 light sensors

8 bit parallel command/data bus

Master controller

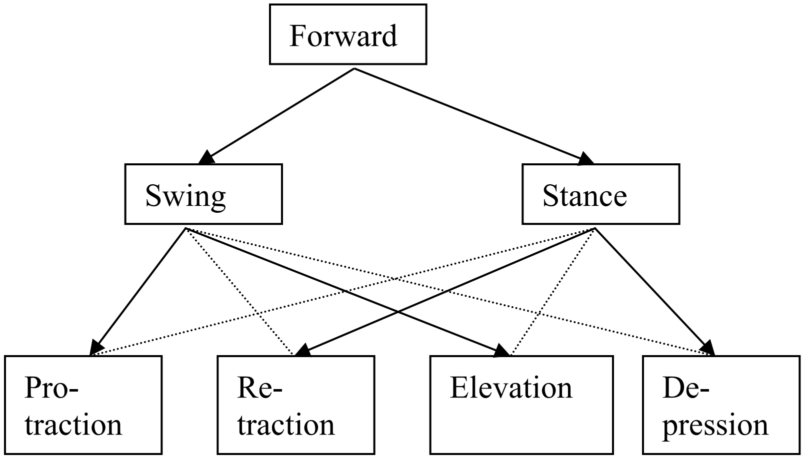
Slave controller

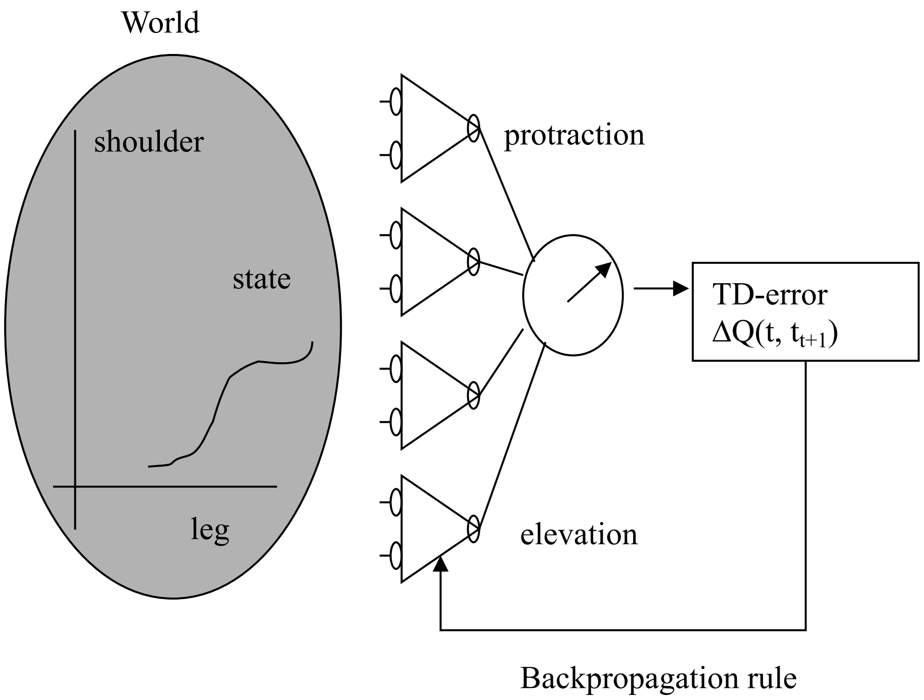


2 dof legs

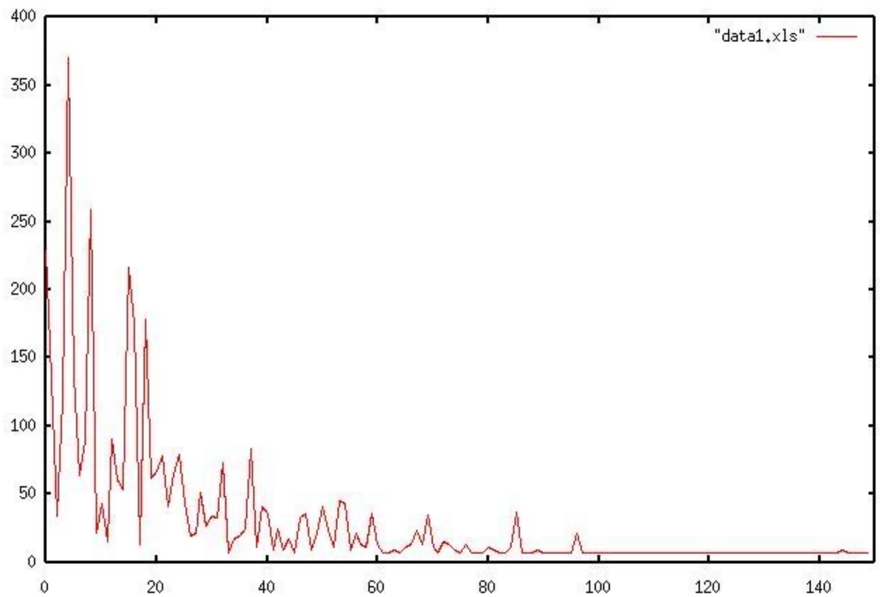
3 segmented design with 2* 2 dof joints

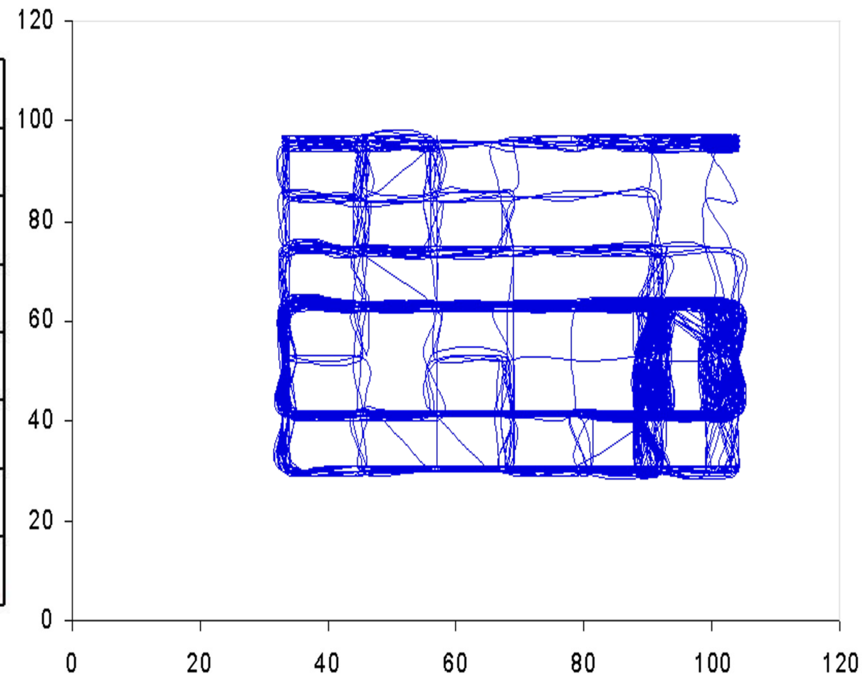
Learning the swing/ stance movements,



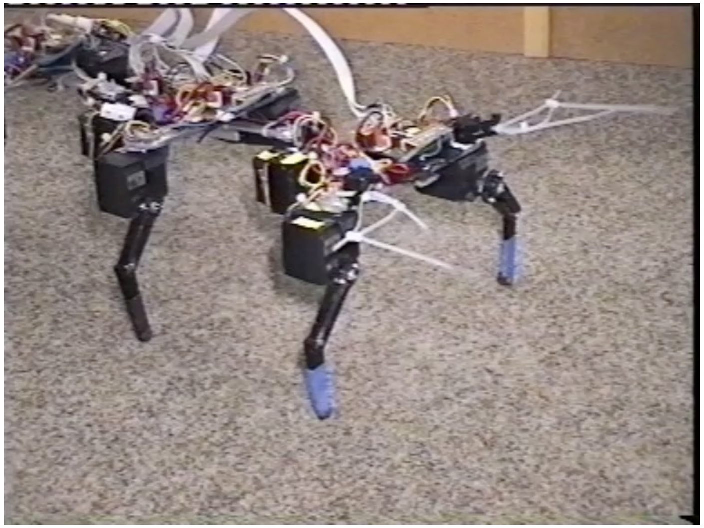


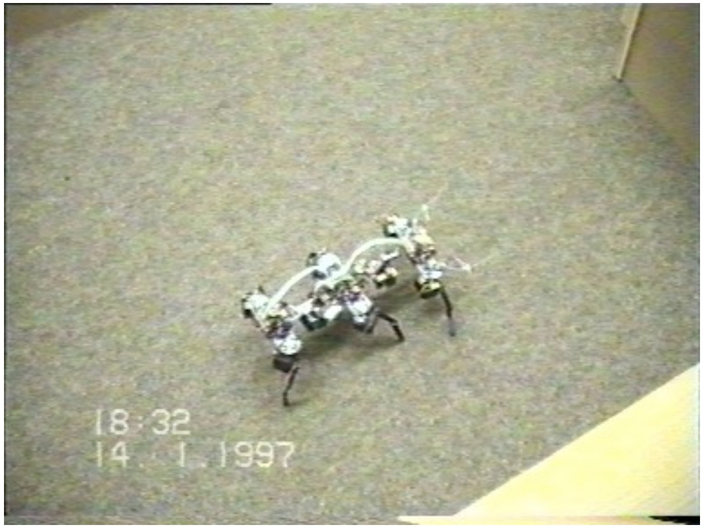
Results learning swing/stance

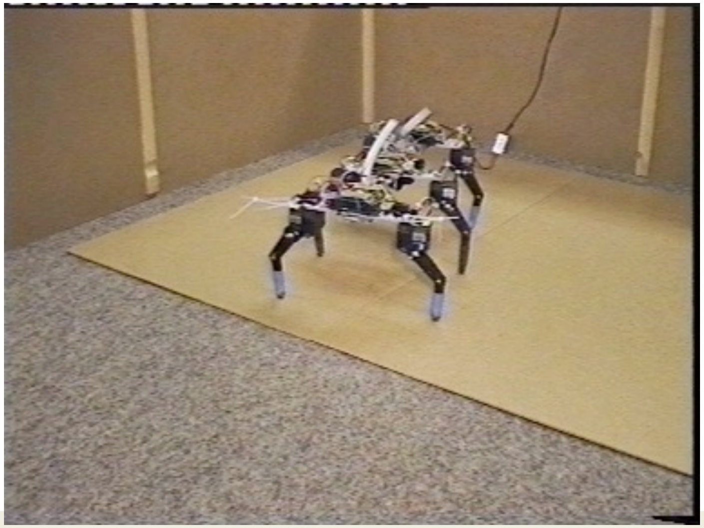




Results learning swing/stance



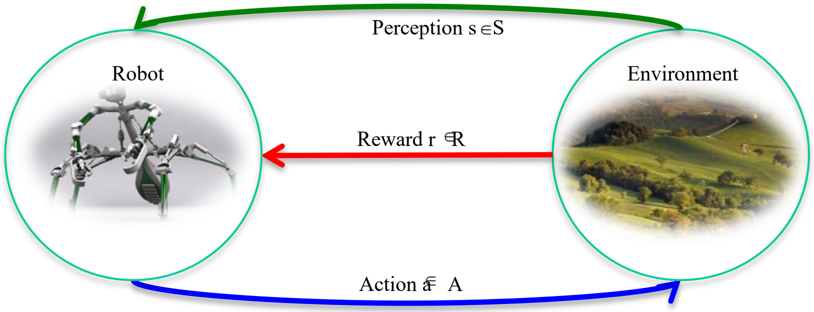




CONCLUSIONS

We got what it takes...

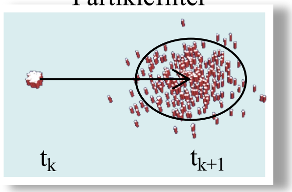
Modell



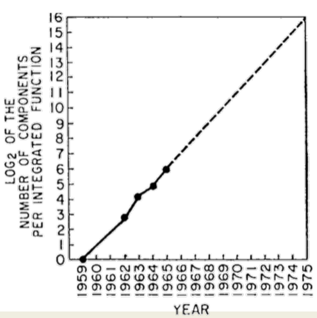
Formalisation & Algorithms

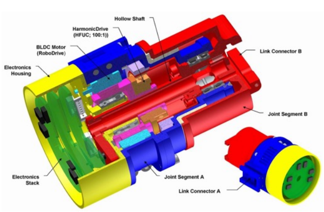
1. [f: S → A]
2. $E\,[r(t) + \Upsilon^1 r(t+1) + \Upsilon^2 r(t+2) + \Upsilon^3 r(t+3) + \ldots] =$ Q(s,a)
3. $P^* = \operatorname{argmax} Q(s^t,a^t),\ t=1,\ldots,\infty$

Partiklefilter

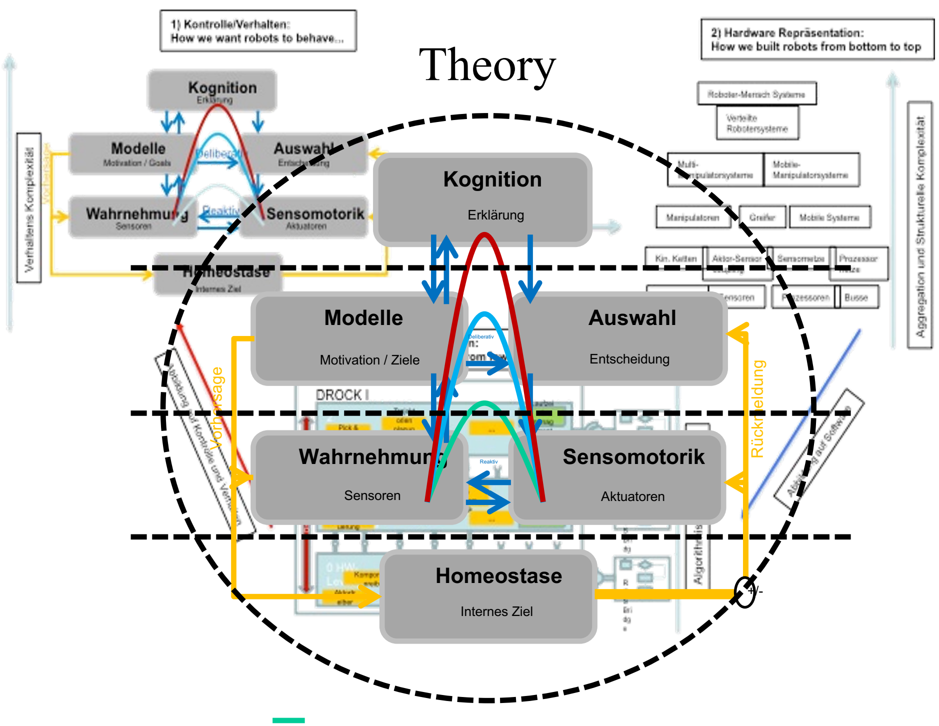


Technology

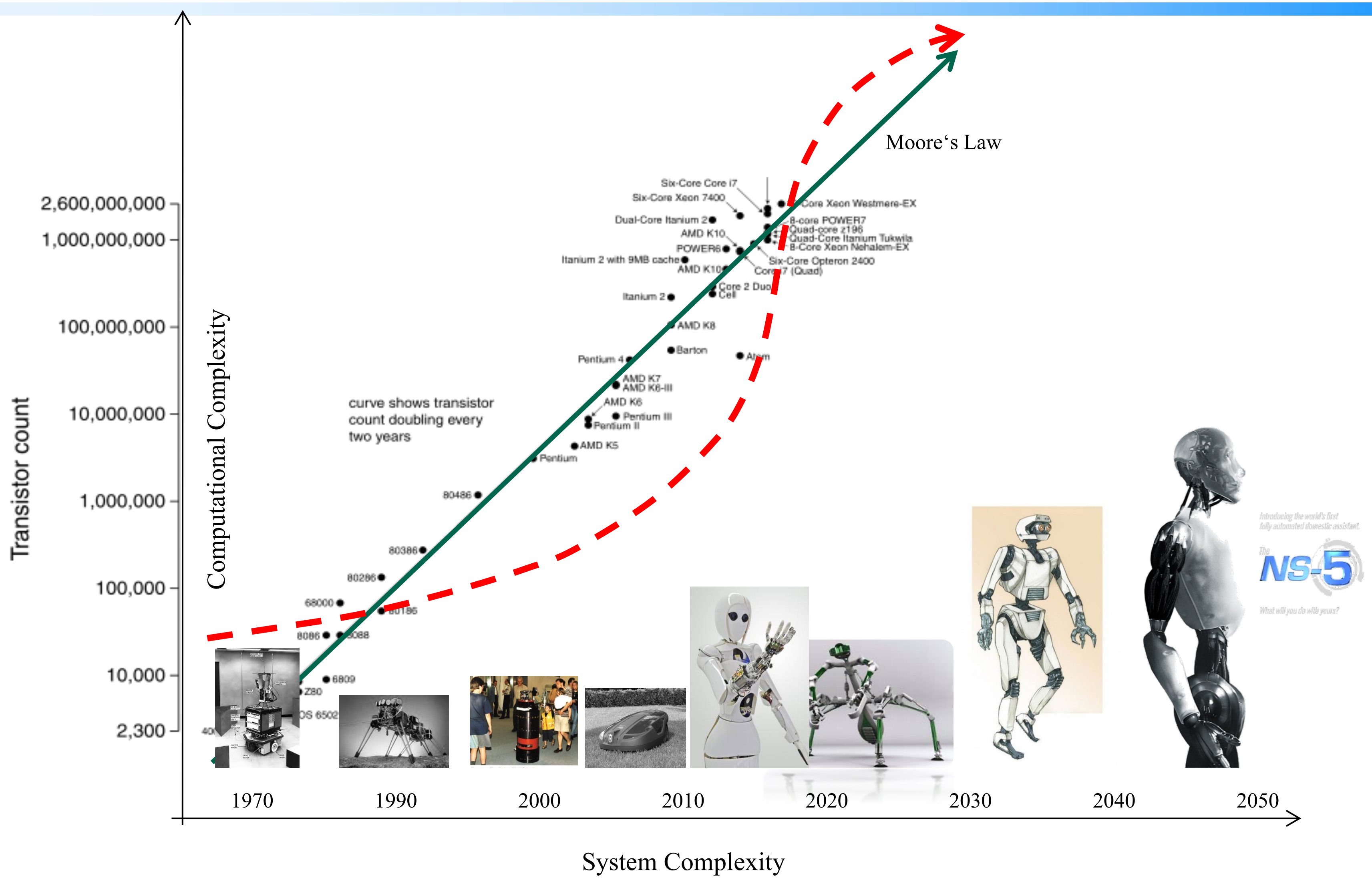




ROCK & DROCK Project



...let‘s not make the same mistakes again...



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Outlook

- Robotics is an interdiciplinary research area
  - Computer science
  - Electrical engineering
  - design
  - materials
  - Neuro science/Psychology
  - ...
- Main research questions
  - System integration tends to even higher complexities (structural/algorithmic)
    - How to ‚manage‘ this complexity?
  - Architectures (HW and SW) for long term autonomous Systems
    - Learning structure and organisation of knowledge instead of accumulating knowledge...
- Goals for the next decade
  - Robots that for for long times in extreme environments
  - Robots that work in so called ‚hybrid social Teams‘ side by side with people