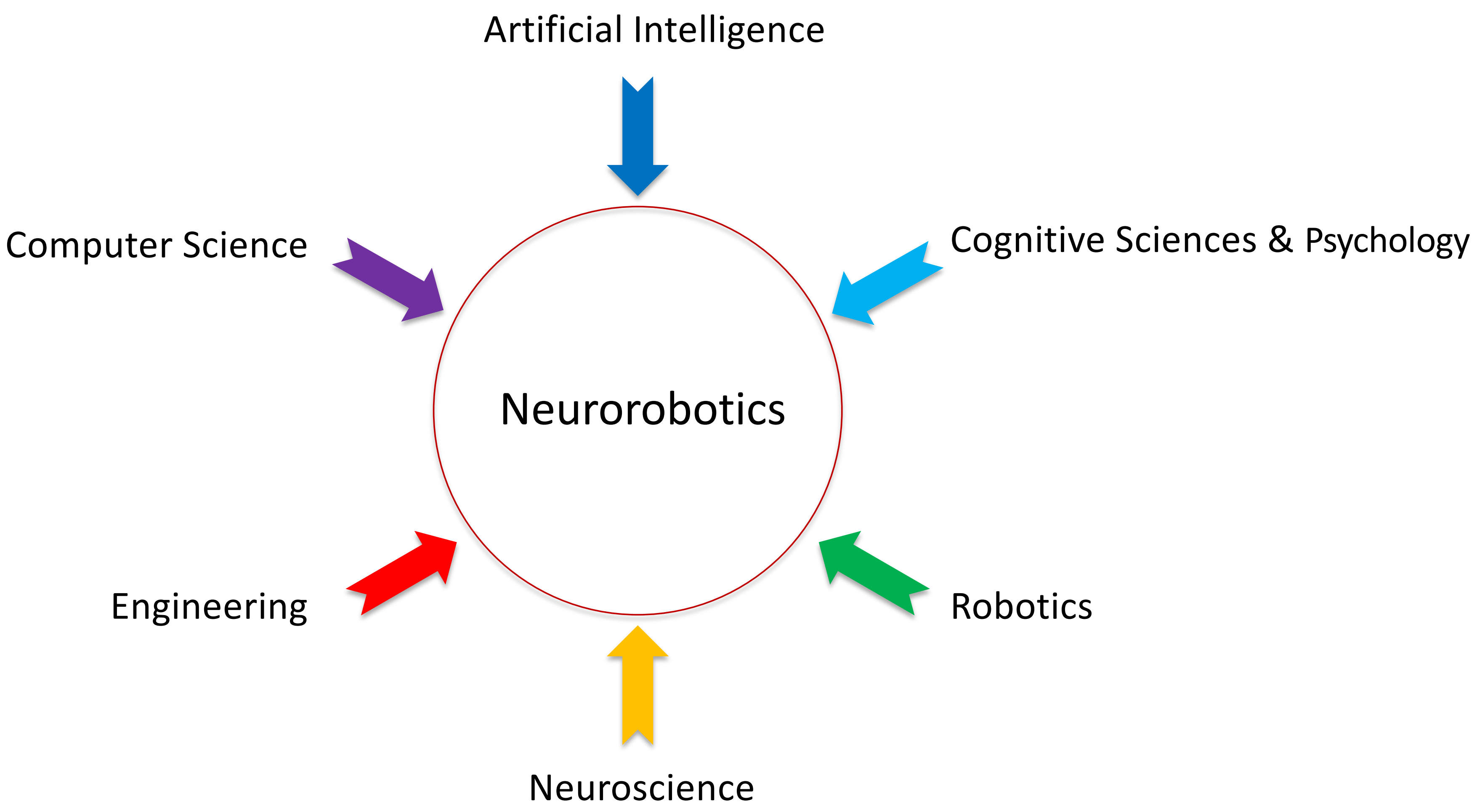
Neurorobotics

Module 1: Background and Foundations

Lecture 1: The Origins of Neurorobotics

David Vernon
Carnegie Mellon University Africa

www.vernon.eu


Artificial Intelligence
Computer Science
Cognitive Sciences & Psychology
Neurorobotics
Engineering
Robotics
Neuroscience

Neurobots

"Autonomous systems
modelled after aspects of the brain"

Used to develop autonomous systems that have the intelligence of biological organisms

Used to study neural function

Sub-discipline of Cognitive Robotics

Focusses on the creation of biologically-inspired robots

along with
Developmental Robotics
Evolutionary Robotics
Soft Robotics
Swarm Robotics

IEEE.org | IEEE *Xplore* Digital Library | IEEE Standards Association | Spectrum Online | More IEEE Sites   Join IEEE | Sign In

TECHNICAL COMMITTEE FOR
NEURO-ROBOTICS SYSTEMS

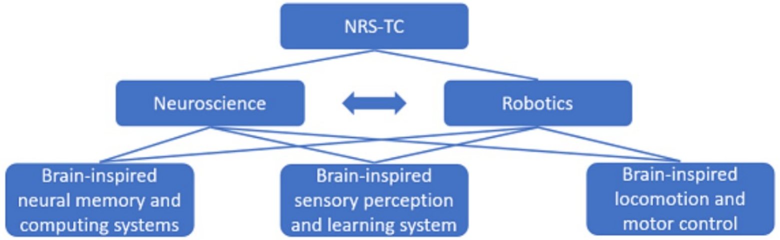
IEEE Robotics & Automation Society   IEEE

DISTINGUISHED LECTURERS   CONTACT   JOIN US

Scope

Neuro-robotics Systems (NRS), a combined study of neuroscience, robotics, and artificial intelligence, is interested in working on models and hardware that promote the fusion of neuroscience and robotics.

- NRS is current state-of-the-art research as branch of neuroscience within robotics
- NRS is a design approach mainly aimed at the fusion of neuroscience and robotics to develop advanced human centered robotic SW/HW.



The mission of the neuro-robotics TC is to provide an entity within the IEEE for neuro-robotics researchers, engineers and practitioners interested to promote neuro-robotics as a research domain.

Committee News

IEEE.org | IEEE *Xplore* Digital Library | IEEE Standards Association | Spectrum Online | More IEEE Sites   Join IEEE | Sign In

TECHNICAL COMMITTEE FOR
COGNITIVE ROBOTICS

ACTIVITIES   RESOURCES   MEMBERS   CONTACT   JOIN US

Scope

There is growing need for robots that can interact safely with people in everyday situations. These robots have to be able to anticipate the effects of their own actions as well as the actions and needs of the people around them.

(Image courtesy of Fraunhofer IPA)

To achieve this, two streams of research need to merge, one concerned with physical systems specifically designed to interact with unconstrained environments and another focussing on control architectures that explicitly take into account the need to acquire and use experience.

The merging of these two areas has brought about the field of *Cognitive Robotics*. This is a multi-disciplinary science that draws on research in adaptive robotics as well as cognitive science and artificial intelligence, and often exploits models based on biological cognition.

Committee News

Technical Commitees

Aerial Robotics and Unmanned Aerial Vehicles
Agricultural Robotics and Automation
Algorithms for Planning and Control of Robot Motion
Automation in Health Care Management
Automation in Logistics

Autonomous Ground Vehicles and Intelligent Transportation Systems
Bio Robotics
Cognitive Robotics
Collaborative Automation for Flexible Manufacturing
Computer & Robot Vision

Cyborg & Bionic Systems
Digital Manufacturing and Human-Centered Automation
Energy, Environment, and Safety Issues in Robotics and Automation
Haptics
Human Movement Understanding

Human-Robot Interaction & Coordination
Humanoid Robotics
Marine Robotics
Mechanisms and Design
Micro/Nano Robotics and Automation

Mobile Manipulation
Model-Based Optimization for Robotics
Multi-Robot Systems
Neuro-Robotics Systems
Performance Evaluation & Benchmarking of Robotic and Automation Systems

Rehabilitation and Assistive Robotics
RoboCup
Robot Ethics
Robot Learning
Robotic Hands, Grasping and Manipulation

Robotics and Automation in Nuclear Facilities
Robotics Research for Practicality
Safety, Security and Rescue Robotics
Semiconductor Manufacturing Automation
Smart Buildings

Soft Robotics
Software Engineering for Robotics and Automation
Space Robotics
Surgical Robotics
Sustainable Production Automation

Telerobotics

Verification of Autonomous Systems
Wearable Robotics
Whole-Body Control

Motivation

Recall: there are two reasons people study neurorobotics

1. Understand cognition

2. Improve autonomous applications

Focus

Development of abilities for

Learning — Adapt to changes and reuse previously learned tasks in new situations

Reasoning — Make inferences about the world and change behaviour accordingly

Exploring — Learn about a new environment and act upon inferences

Communicating — Interact with humans and other agents, enabling teamwork and cooperation

Cybernetics and Connectionism

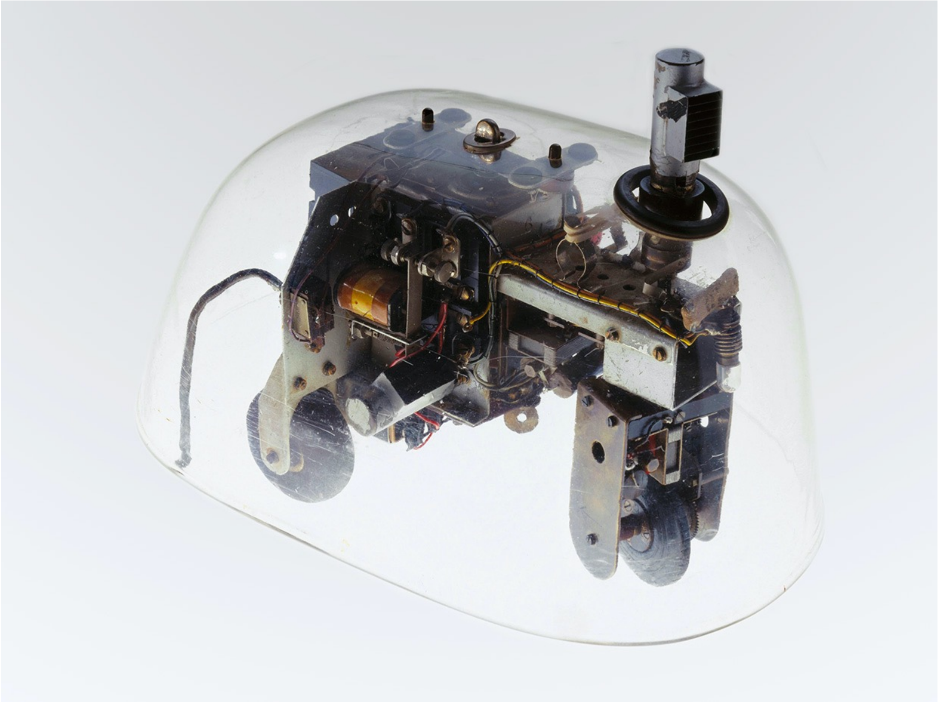
W. Grey Walter's Tortoises (1950)

Neurophysiologist W. Grey Walter built two cybernetic tortoises to understand the functions of the brain

He nicknamed them

ELSIE (Electro-mechanical robot, Light-Sensitive with Internal and External stability) and

ELMER (ELectro-MEchanical Robot)



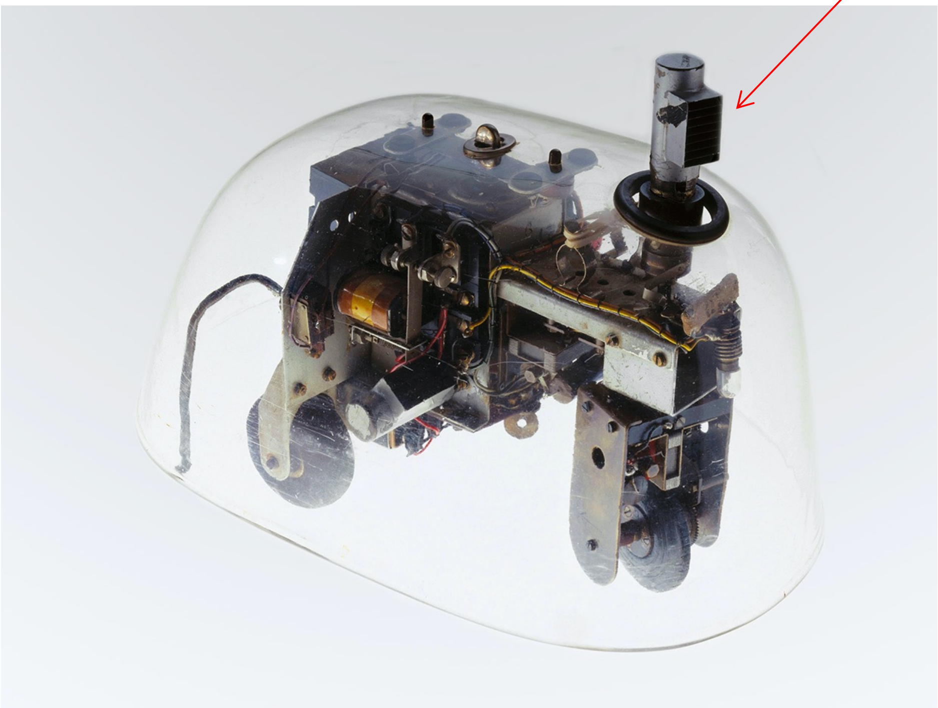
Meet the Roomba's Ancestor: The Cybernetic Tortoise, IEEE Spectrum, 2020
https://spectrum.ieee.org/tech-history/space-age/meet-roombas-ancestor-cybernetic-tortoise

Early Examples of Neurorobots

W. Grey Walter's Tortoises (1950)

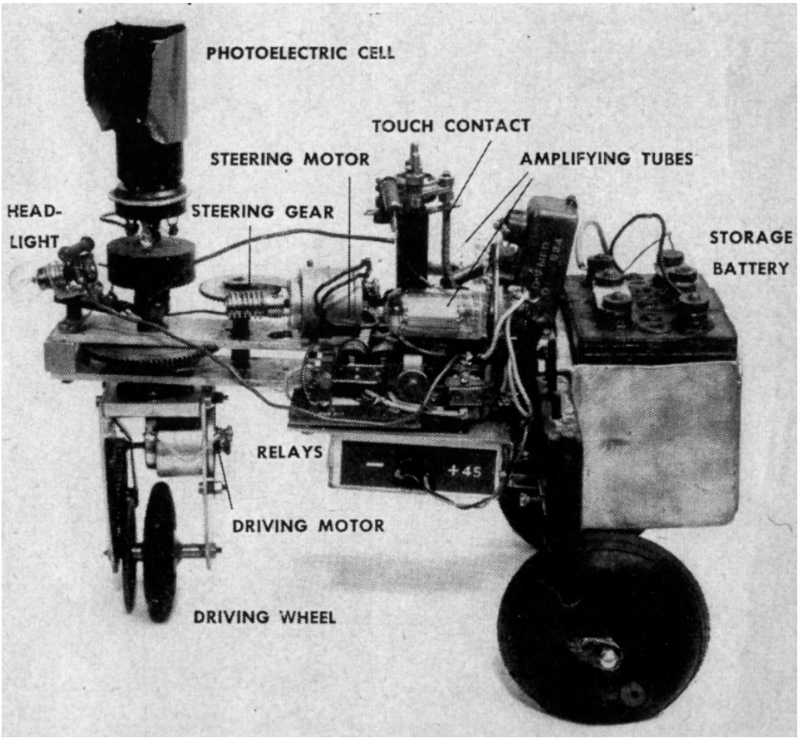
- Roam around a room
- Find a charging station
- Recharge themselves.

"With just a photocell, a touch sensor, and two vacuum tubes, the robo-tortoise mimicked the way real animals move" (Marsh, 2020)



Meet the Roomba’s Ancestor: The Cybernetic Tortoise, IEEE Spectrum, 2020
https://spectrum.ieee.org/tech-history/space-age/meet-roombas-ancestor-cybernetic-tortoise

Early Examples of Neurorobots



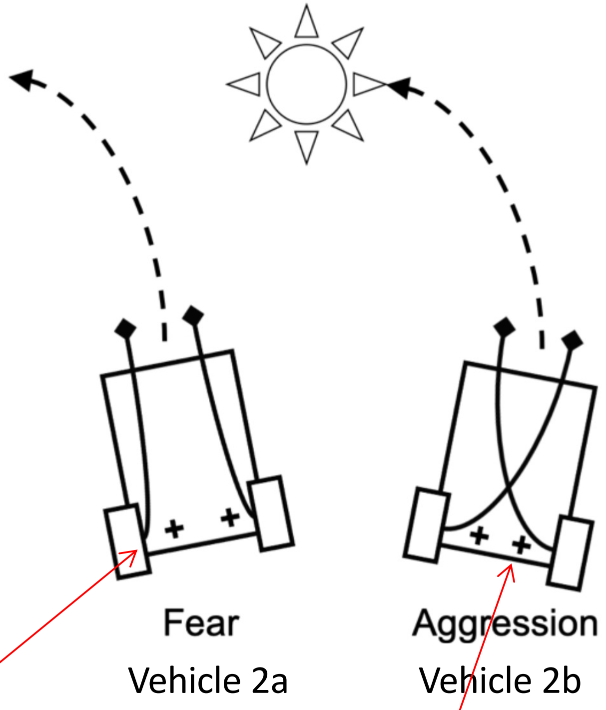
Left: Picture taken of Grey Walter and his wife Vivian with the Elsie and Elmer tortoises. Right: Labelled picture of Elsie without her shell.

Photos taken from http://cyberneticzoo.com.

Early Examples of Neurorobots

Valentino Braitenberg's Vehicles

- Thought experiments
- Vehicles 2 and 3: Left and right motors turn wheels
- Vehicles 2 and 3: Left and right light sensors
- Sensors are connected to motors
  - Excitatory connection (+)
  - Inhibitory connection (-)
  - Ipsilateral connection (same side)
  - Contralateral (opposite side)



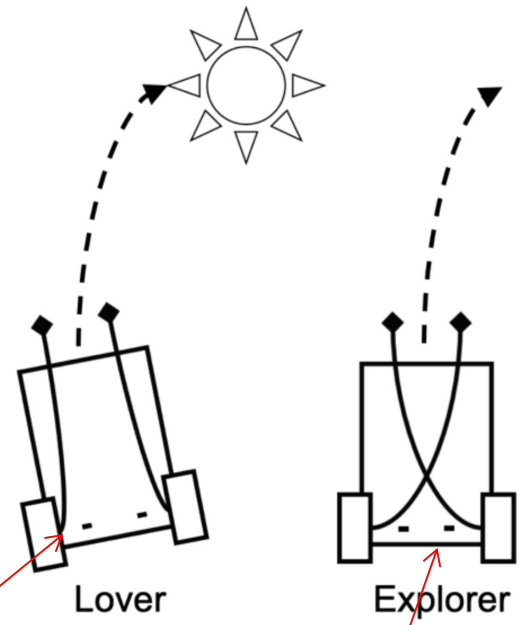
Ipsilateral excitatory connection
More light right → right wheel turns faster
→ turns towards the left, away from the light.

Contralateral excitatory connection
More light left → right wheel turns faster
→ turns towards the left, towards the light

Early Examples of Neurorobots

Valentino Braitenberg's Vehicles

- Thought experiments
- Vehicles 2 and 3: Left and right motors turn wheels
- Vehicles 2 and 3: Left and right light sensors
- Sensors are connected to motors
  - Excitatory connection (+)
  - Inhibitory connection (-)
  - Ipsilateral connection (same side)
  - Contralateral (opposite side)



Vehicle 2a

Vehicle 2b

Ipsilateral inhibitory connection
More light right → right wheel turns slower
→ turns towards the right, towards from the light, but slowing down as it approaches

Contralateral inhibitory connection
More light left → right wheel turns slower
→ turns towards the right, away from the light, but slowing down as it approaches, and then move away

Early Examples of Neurorobots

In the brain

- Most connections in the nervous system are contralateral
- Some are ipsilateral
- There is a balance of excitatory and inhibitory connections
  - Generating
  - Releasing
  - Suppressing

  behaviours

Robotics

Autonomy

- The ability to operate in a real-world environment for an extended period, without any form of external control

Robotics

Sensors

- Exteroceptive: sense the external world
  - vision, hearing, smell, touch, taste
- Interoceptive: sense the internal system
  - e.g. inner ear / vestibular system for balance and acceleration
  - proprioception: forces and loads on your joints and muscles
  - autonomic nervous system: energy levels, temperature, heart rate, ….

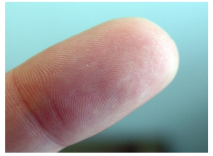
Seeing

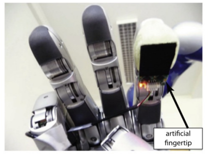
Stereo camera

Hearing

Binaural microphones

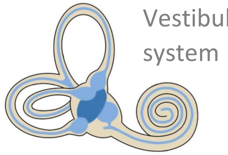
Touching



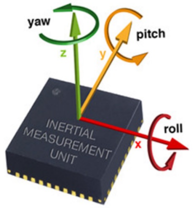


Tactile sensors

Feeling Motion



Vestibular system

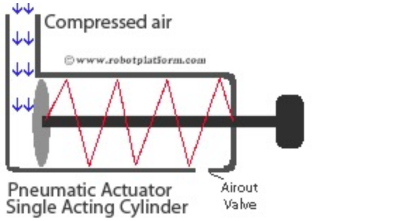


Inertial Measurement Unit (IMU)

Robotics

Actuators

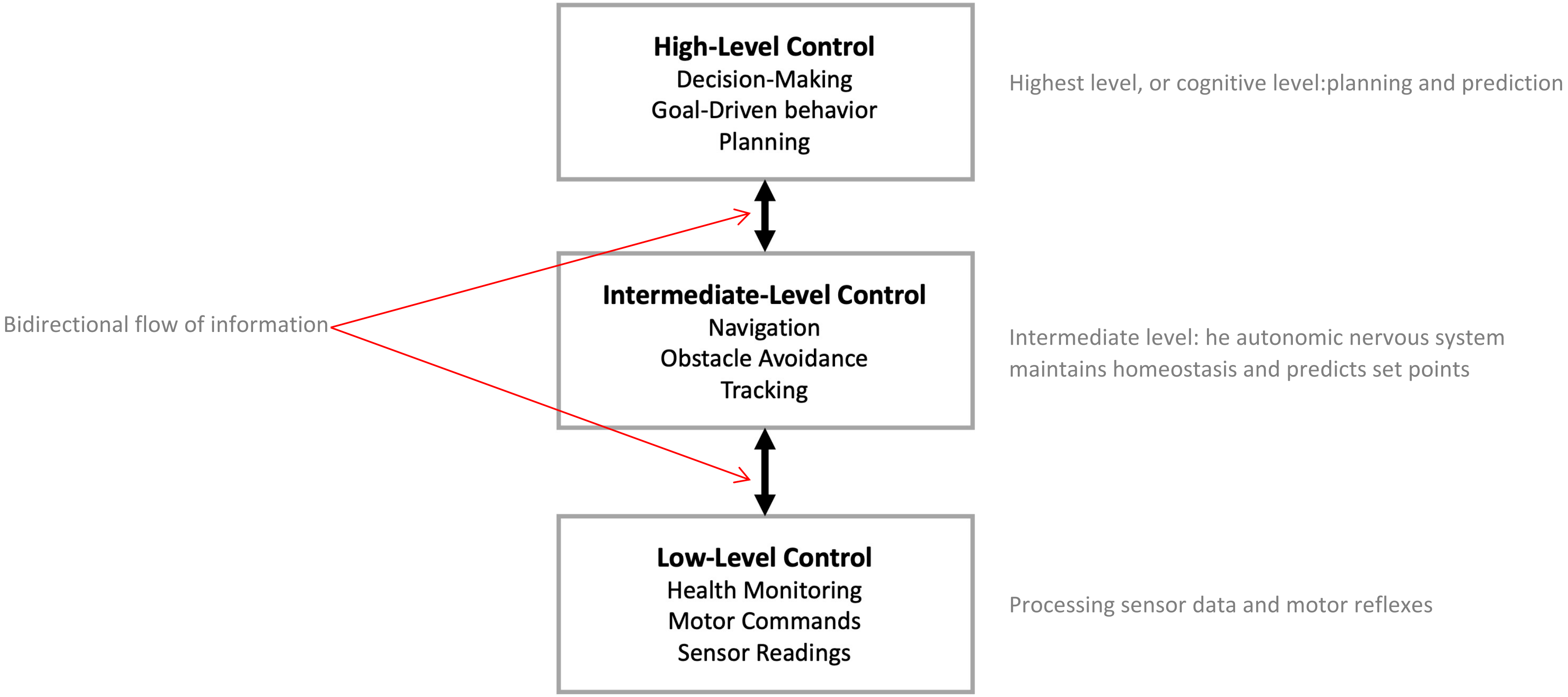
- Combined with effectors (e.g. legs, arms, hands, …)
- Provide a means to physically interact with the environment
- Electric motors typically drive the effectors
- Pneumatic actuators
- Hydraulic actuators



http://www.robotplatform.com/knowledge/actuators/types_of_actuators.html

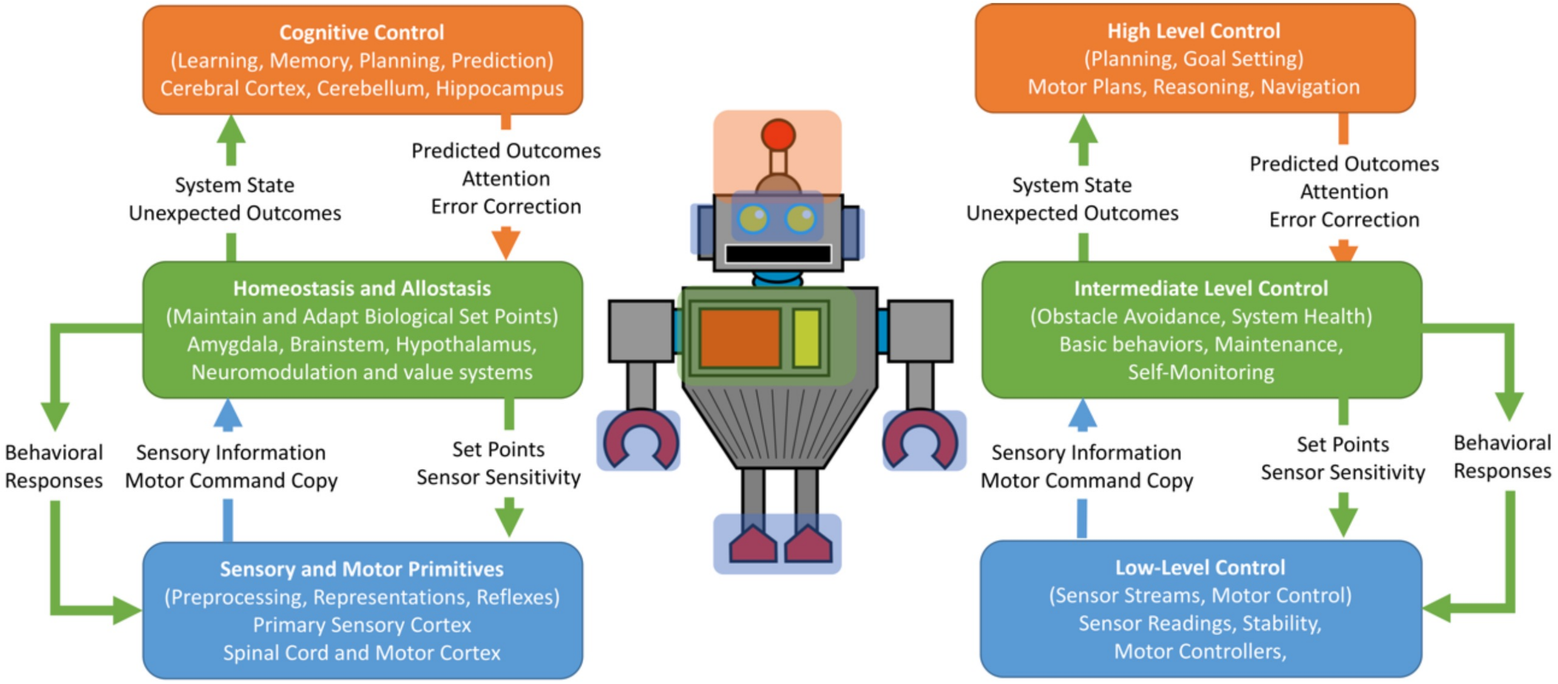
Robotics

We distinguish three levels of control in neuroscience and robotics



Robotics

Self-monitoring systems in biology and engineering

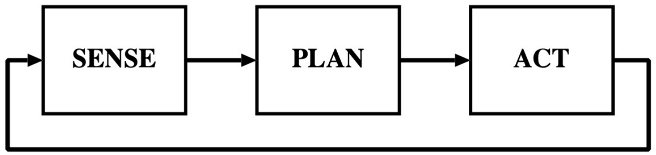


From (Chiba and Krichmar, 2020)

Robotics

Software architectures

- Sense-think-act / Sense-plan-act / Deliberative / Hierarchical



Input sensory data

Processed into abstract representations

Analyzed to plan the next action

Output the action motor commands

Robotics

Software architectures

- Sense-think-act / Sense-plan-act / Deliberative / Hierarchical
- Reactive: robots responded immediately and reflexively to environmental cues

Act first; think later

Multiple instances of Sense-Act couplings called sensorimotor contingencies or behaviors

Each behavior operates in parallel

Advantage: immediately respond to an external event

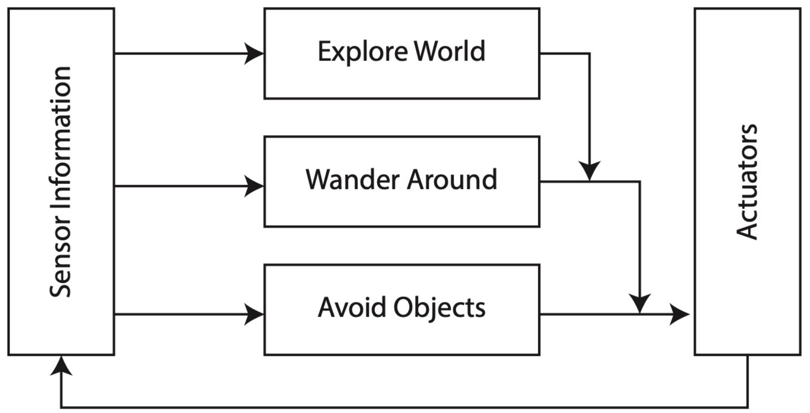
Robotics

Software architectures

- Sense-think-act / Sense-plan-act / Deliberative / Hierarchical
- Reactive
- Behaviour-based
  - Invoke mechanisms to mediate between which behaviors are active and which are not
    - Schemas: different recombinable schemas for different actions or sensor states
    - Arbitration rules (e.g. subsumption architecture) allow one function to interrupt or override others
  - Motivated by the belief that effective robot control could be achieved faster and more efficiently by responding to the dynamics of the world rather than building and maintaining a world model

Robotics

The subsumption architecture organizes behaviors into hierarchies



Robotics

Software architectures

- Sense-plan-act / Deliberative / Hierarchical
- Reactive
- Behaviour-based
- Hybrid of deliberative and reactive
  - A reactive control layer that responds quickly to sub-second social events
  - A deliberative layer that formulates a predictive (prospective) response to slower elements

Neurorobotic Approach

Neurorobotics has strong foundations in behavioral neuroscience

- So, adopting ideas from the behavior-based approach is appealing to neuroroboticists
- Although the brain does build models of the world to predict outcomes, the nervous system and organism are very responsive to environmental events
- Reflexes at the spinal cord and attention to change operate rapidly, involuntarily, and often without conscious awareness
- It is only after the event and our response occurs that we become aware of what just happened and take appropriate planning or corrective actions
- An important observation of the early behavior-based robots was that their behavior looked much more natural than existing robots.

Neurorobotic Approach

A neurorobot controller should follow the architecture and dynamics of a real nervous system

- It should have homologs to different brain regions
- It typically will have **neurons** and **synapses** (i.e., connections) that have some degree of bio-realisM
- The neurorobot artificial nervous system is described with pathways connecting brain regions having a variety of connectivity patterns
    - Contrast this with the regular feedforward architecture of an artificial neural network, with layers of input, hidden, and output neurons
- These connections are often plastic and must support online learning
    - Biological organisms do not have separate training and testing periods
    - They may have some innate capabilities but must learn through their own experiences.

Neurorobotic Approach

No two neurorobots are alike

- Even though they share the same robot body and have similar artificial brains
- Their experience shapes their behavior
- Behaviour can shape their nervous systems
  - Experience can change the way neurons respond over time
  - and can cause rewiring of the synapses in the neural network

Reading

Hwu, T. and Krichmar, J. (2022). Neurorobotics: Connecting the Brain, Body and Environment, MIT Press.

Chapter 1 – Neurorobotics: Origins and Background, pp. 1-15

Videos

Daniel Wolpert TED Talk on the real reason for brains

https://www.youtube.com/watch?v=7s0CpRfyYp8

Cognitive Architectures for Robot Agents:

a collection of 15 talks from leading experts

https://transair-bridge.org/workshop-2021/

One of which is Jeffrey Krichmar, University of California; the title of this talk is Neurorobotics: Connecting the Brain, Body and Environment

https://youtu.be/rb2OQH7ghW8