Robotbilime Giriş

Emre Uğur
Bilgisayar Mühendisliği
Boğaziçi Üniversitesi

Bogazici University

- From Spring 2016.
- Teaching
  - Artificial Intelligence
  - Machine Learning
  - Robot Learning
  - Introduction to Cognitive Science
- Projects
  - BAP Start-up: Learning in Cognitive Robots
  - TUBITAK 2232: Sağlarlık güdümlü karmaşık manipülasyon ögrenme çerçevesi
  - H2020-ICT-RIA: Robots Understanding Their Actions by Imagining Their Effects
  - BAP M: Imagining Other's Goals in Cognitive Robots (IMAGINE - COG)

COLORS Lab

Cognitive Learning and Robotics

- Homepage
- Projects
- Student Projects
- People
- Publications
- News & Events
- Contact

Cognition, Learning and Robotics

Welcome to the website of the CoLoRs Group in Dept. of Computer Engineering, Bogazici University.

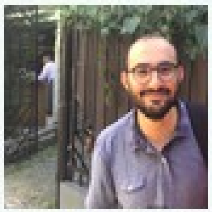
News & Events

- Melisa Sener is visiting Nagai Group, International Research Center for Neurointelligence, The University of Tokyo, as an intern student from July to August 2019.
- Our paper titled "Effect regulated projection of robot's action space for production and prediction of manipulation primitives through learning progress and predictability based exploration" is accepted to **TCDS 2019!**
- Our paper titled "Deep Effect Trajectory Prediction in Robot Manipulation" is accepted to **RAS 2019!** pdf, video.
- Our paper titled "Conditional Neural Movement Primitives" is accepted to **RSS 2019!** pdf, video.
- Our work received Best Poster Award in **ToRK2019!** link
- Our research has appeared in Deutsche Welle Turkce Servisi. Accessible via youtube link.
- Emre Ugur is invited speaker in International Mini-Symposium on Cognitive Robotics, Osaka, Japan, August 2018.
- Serkan Bugur is visiting Nagai Group, National Institute of Information and Communications Technology (NICT), as an intern student from September to October 2018.
- Our research has appeared in national newspapers Hürriyet and Sabah. Accessible via Hürriyet and Sabah.
- Hakan Girgin is visiting Robot Learning and Interaction (RLI) Group, at Idiap Research Institute as an intern student from March to September 2018.
- Our research appeared in national news channel Haberturk! See video.
- Mert Imre and Ahmet Ercan Tekden are visiting Nagai Group, National Institute of Information and Communications Technology (NICT), as intern students.

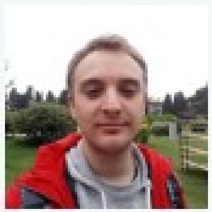
People

Emre Ugur
Head of Research Group

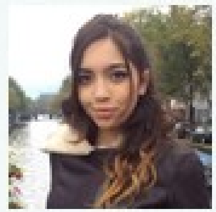
PhD Students



Serkan Bugur

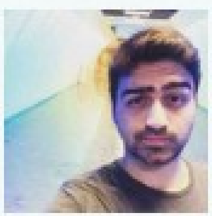


Alper Ahmetoglu

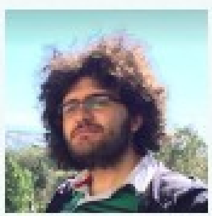


Ece Ada

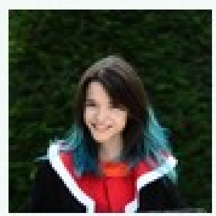
MSc Students



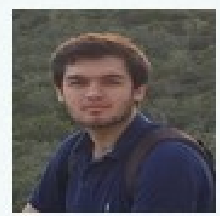
M. Yunus Seker



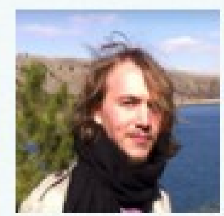
Ahmet Tekden



Melisa Sener



Tuluhan Akbulut



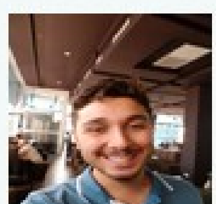
Hamit Basgol

Utku Bozdogan

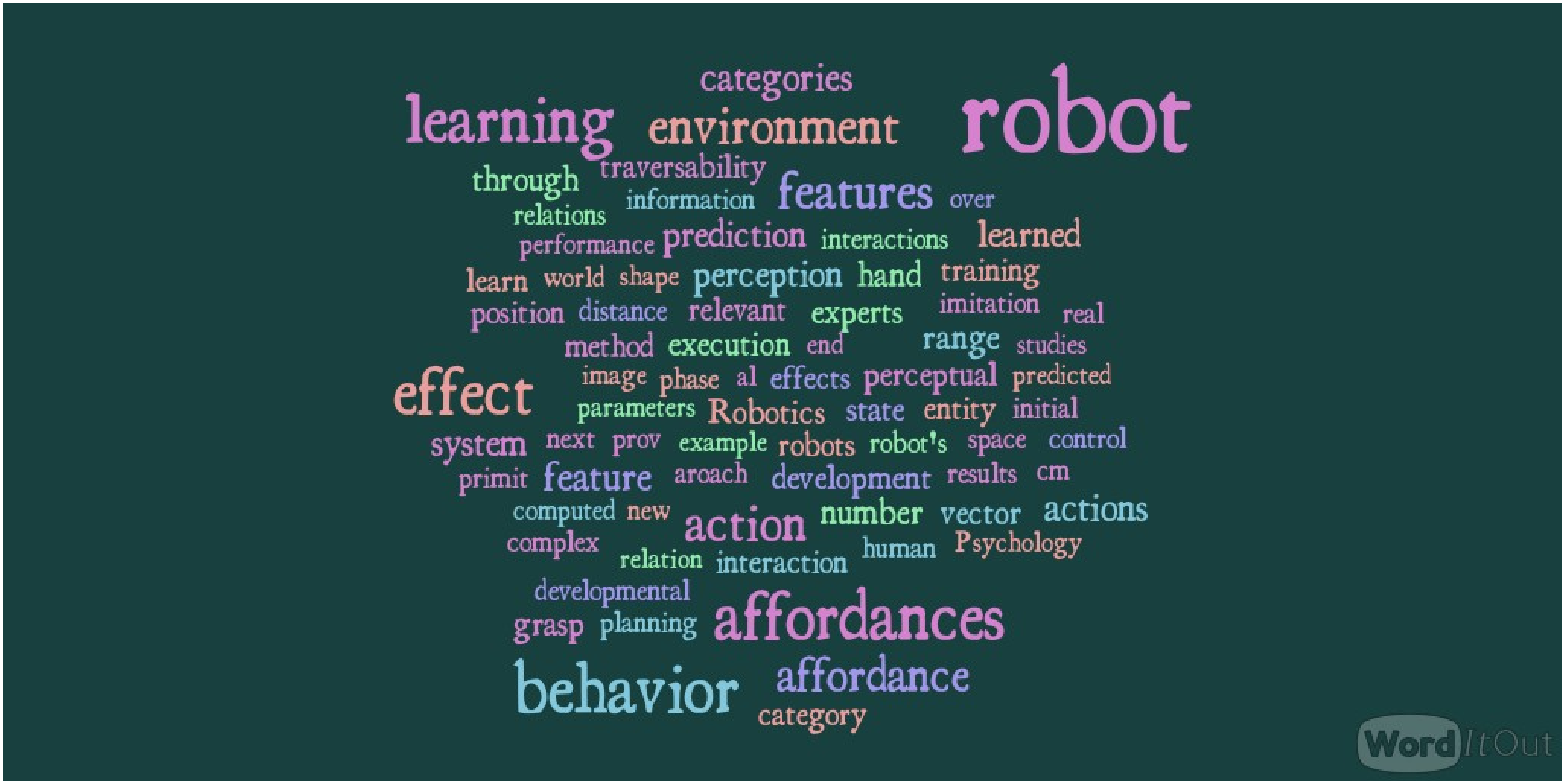
Bachelor Students

Aysu Sayın

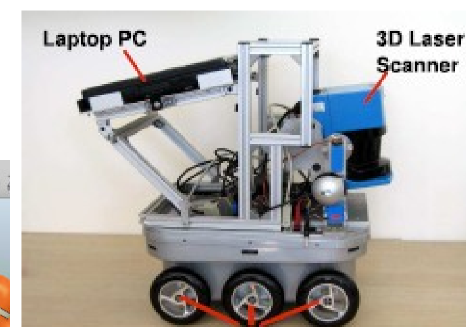
Irmak Güzey



Ege Onur Taga



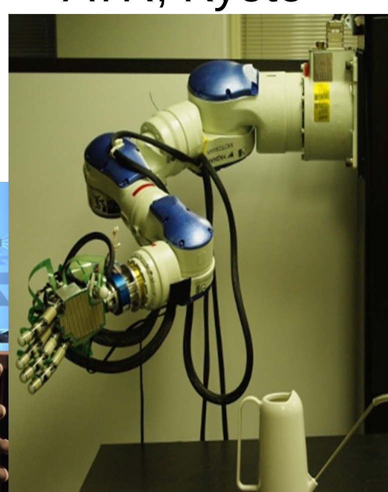
METU

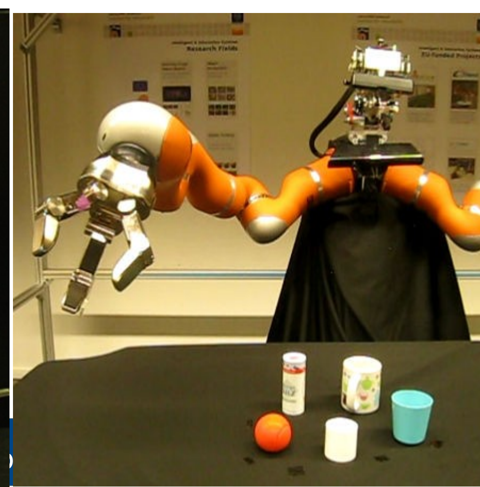


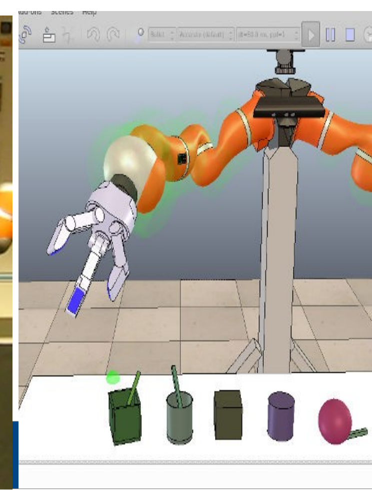
ATR, Kyoto

Innsbruck Univ.

Osaka Univ.



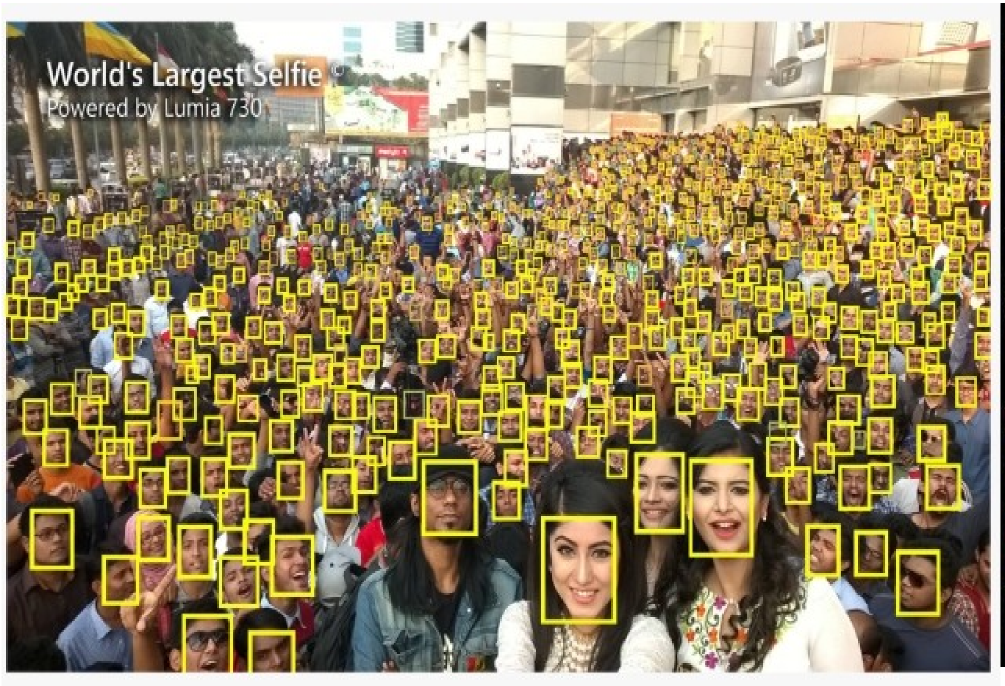


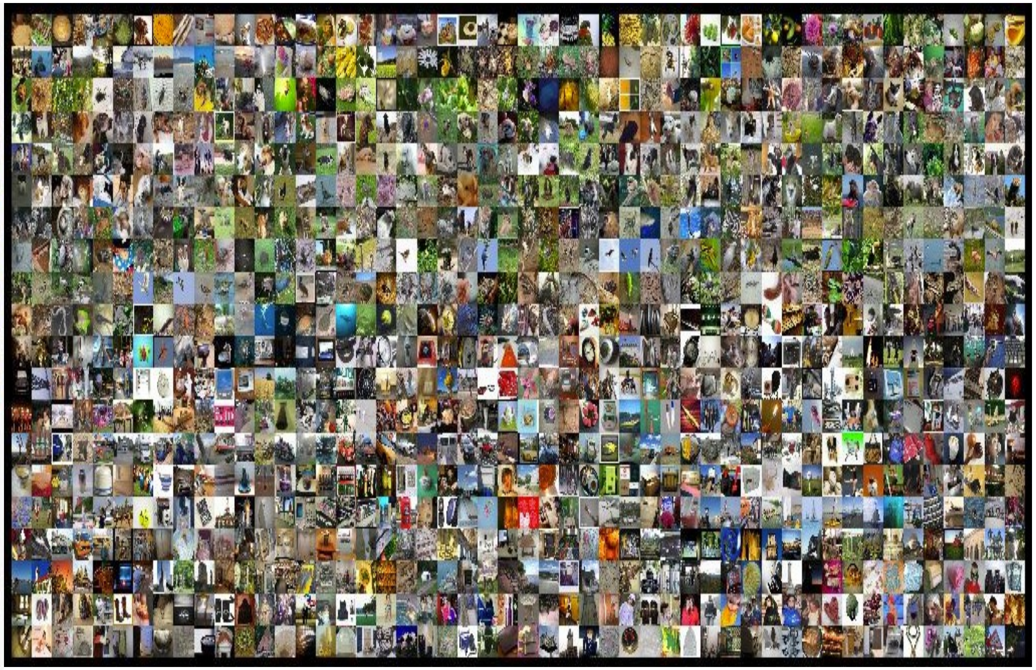


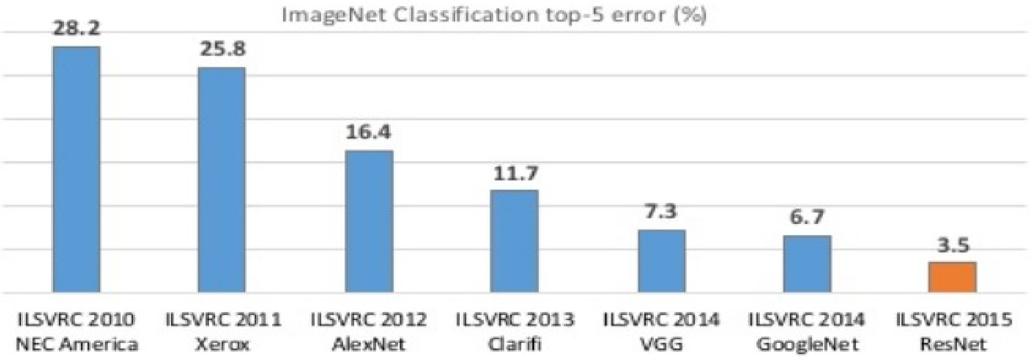
Robotlarda problemler, beceriler

Terminator 2: Judgment Day (1991)

Robotlarda problemler
Görü/algı

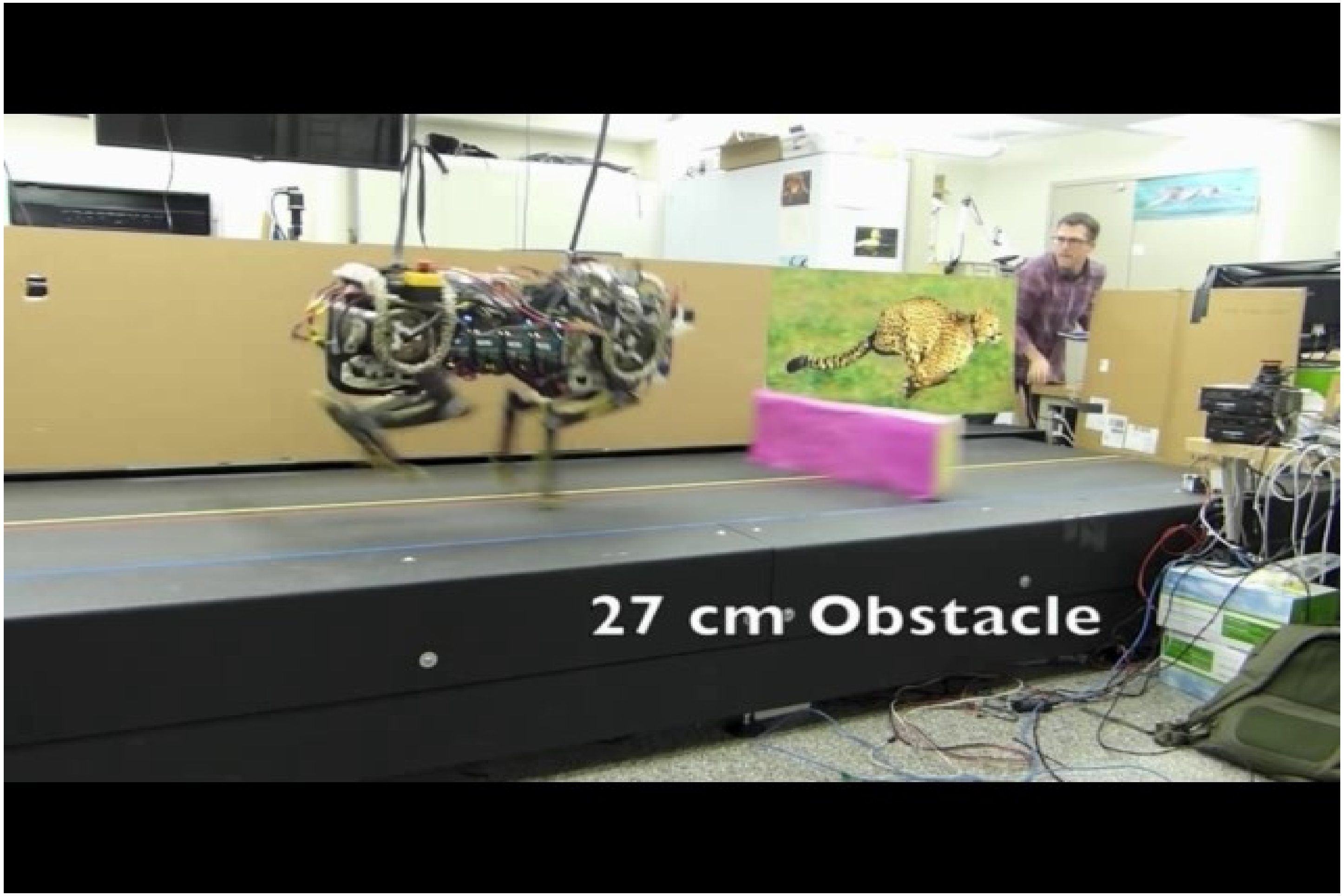






Robotlarda problemler
Denge/yürüme

Robotlarda problemler
Denge/yürüme



MIT cheetah

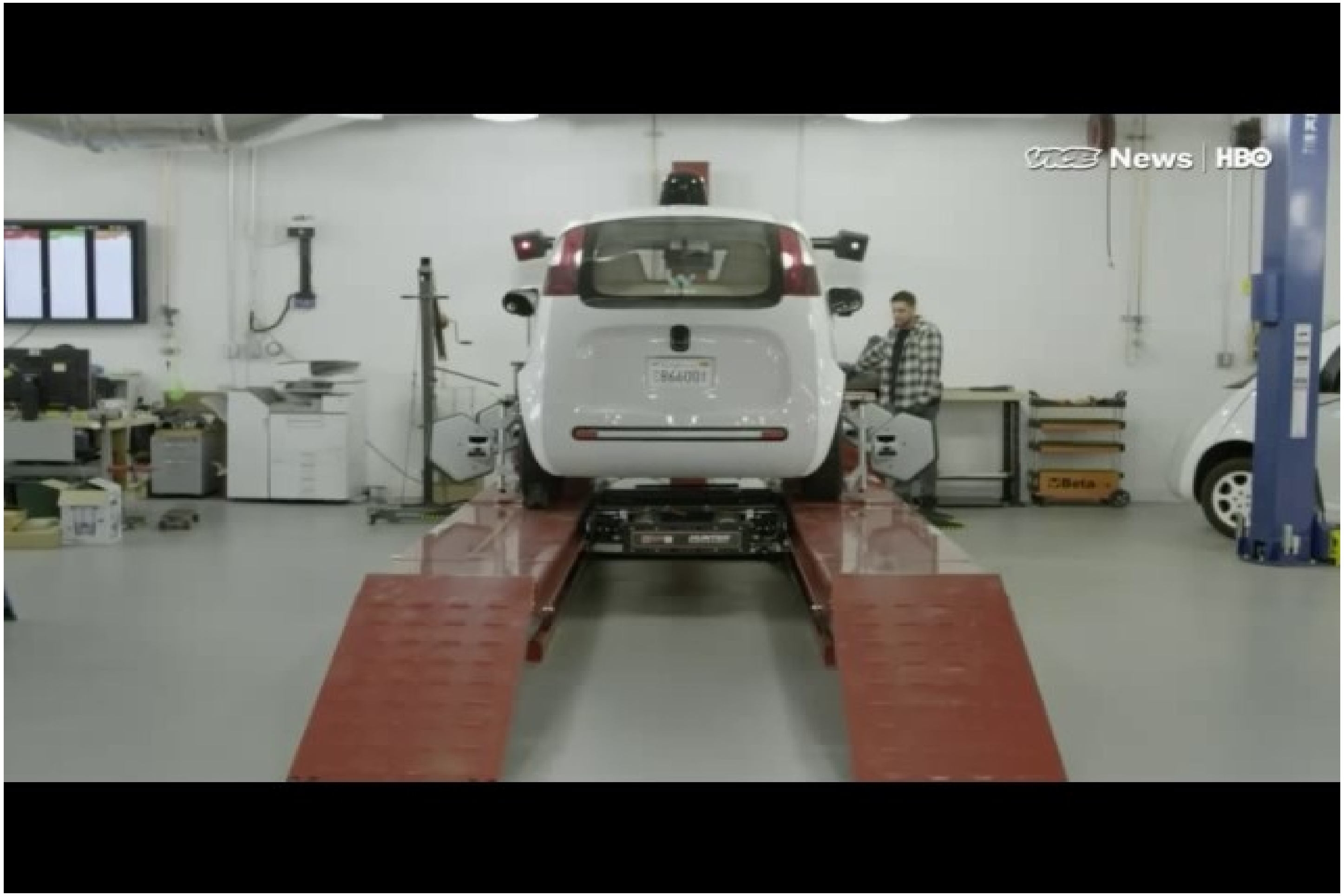
Robotlarda problemler
Denge/yürüme

Atlas

Robotlarda problemler
Denge/yürüme

https://www.youtube.com/watch?v=g0TaYhjpOfo&t=6s

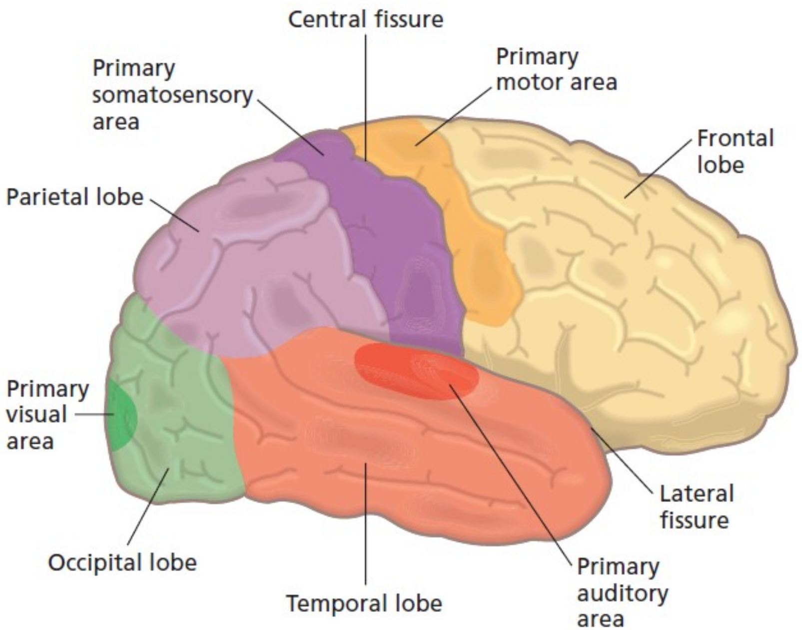
Robotlarda problemler
Hareket ve yön bulma

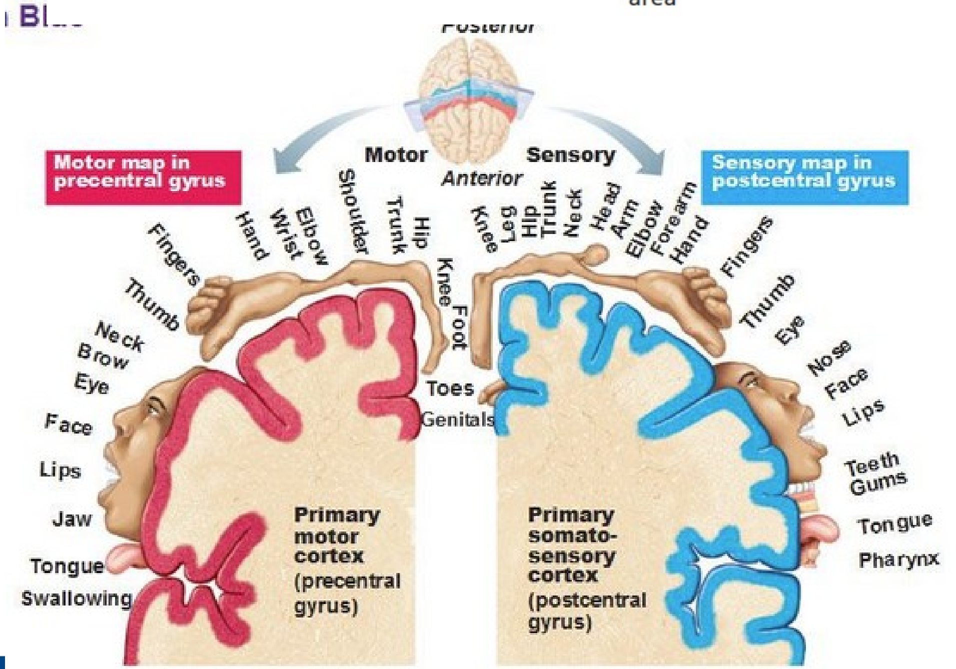


https://www.youtube.com/watch?v=qtApzKnGU94

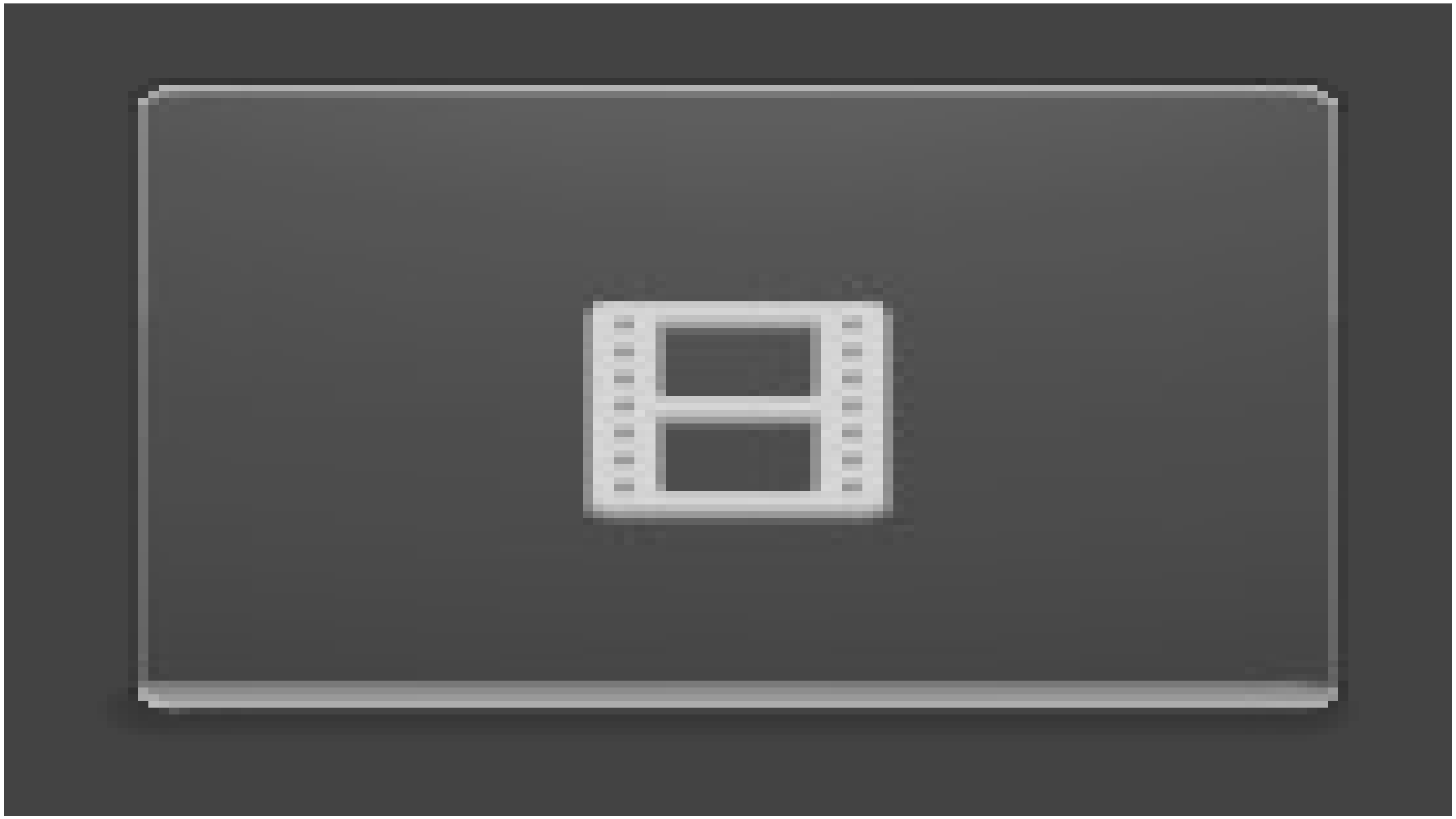
Robotlarda problemler
Manipülasyon

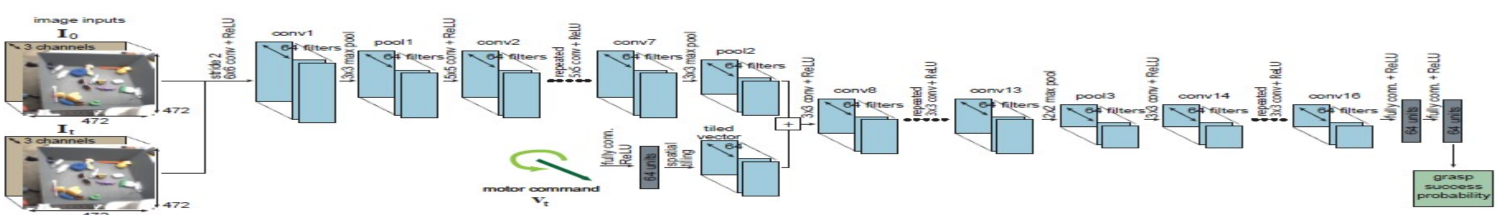
Robotlarda problemler
Manipülasyon





Robotlarda problemler
Manipülasyon



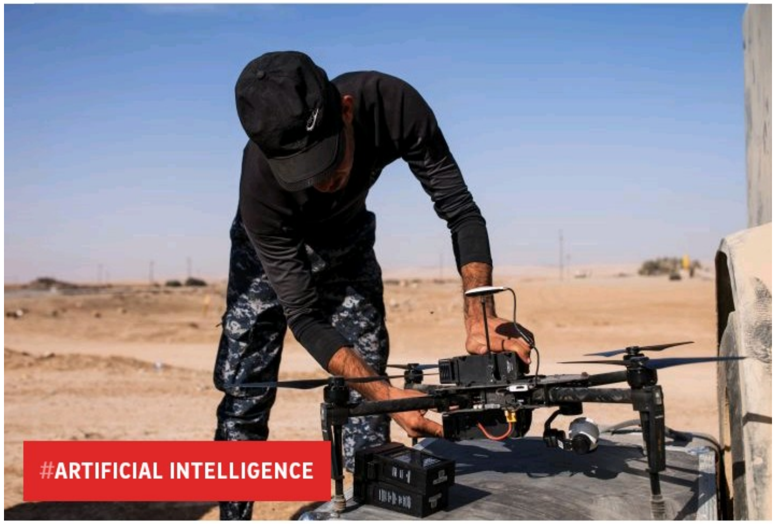


800K grasp attempts, 2 months, 6-14 robots

S. Levine, P. Pastor, A. Krizhevsky, and D. Quillen. Learning hand-eye coordination for robotic grasping with large-scale data collection. In International Symposium on Experimental Robotics (ISER 2016) , 2016.

https://www.youtube.com/watch?v=iaF43Ze1oeI

Robotlarda problemler
Planlama, muhakeme, karar verme



Elon Musk and AI Experts Call for Total Ban on Robotic Weapons

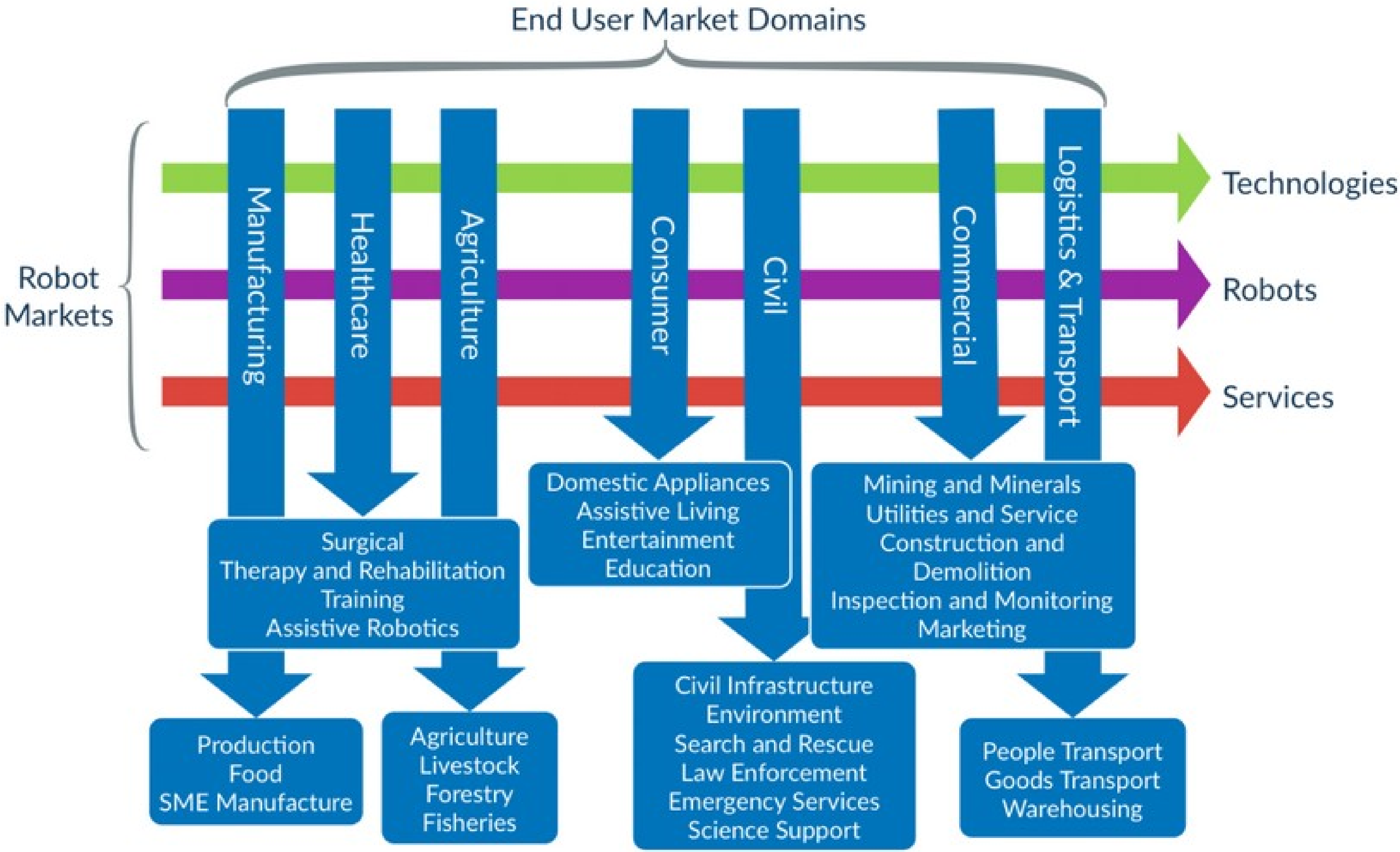
Fortune · 14s · David Z. Morris

116 roboticists and A.I. researchers, including SpaceX founder Elon Musk and Google Deepmind co-founder Mustafa Suleyman, have signed a letter to the United Nations calling for strict oversight of ...

Robotic Applications

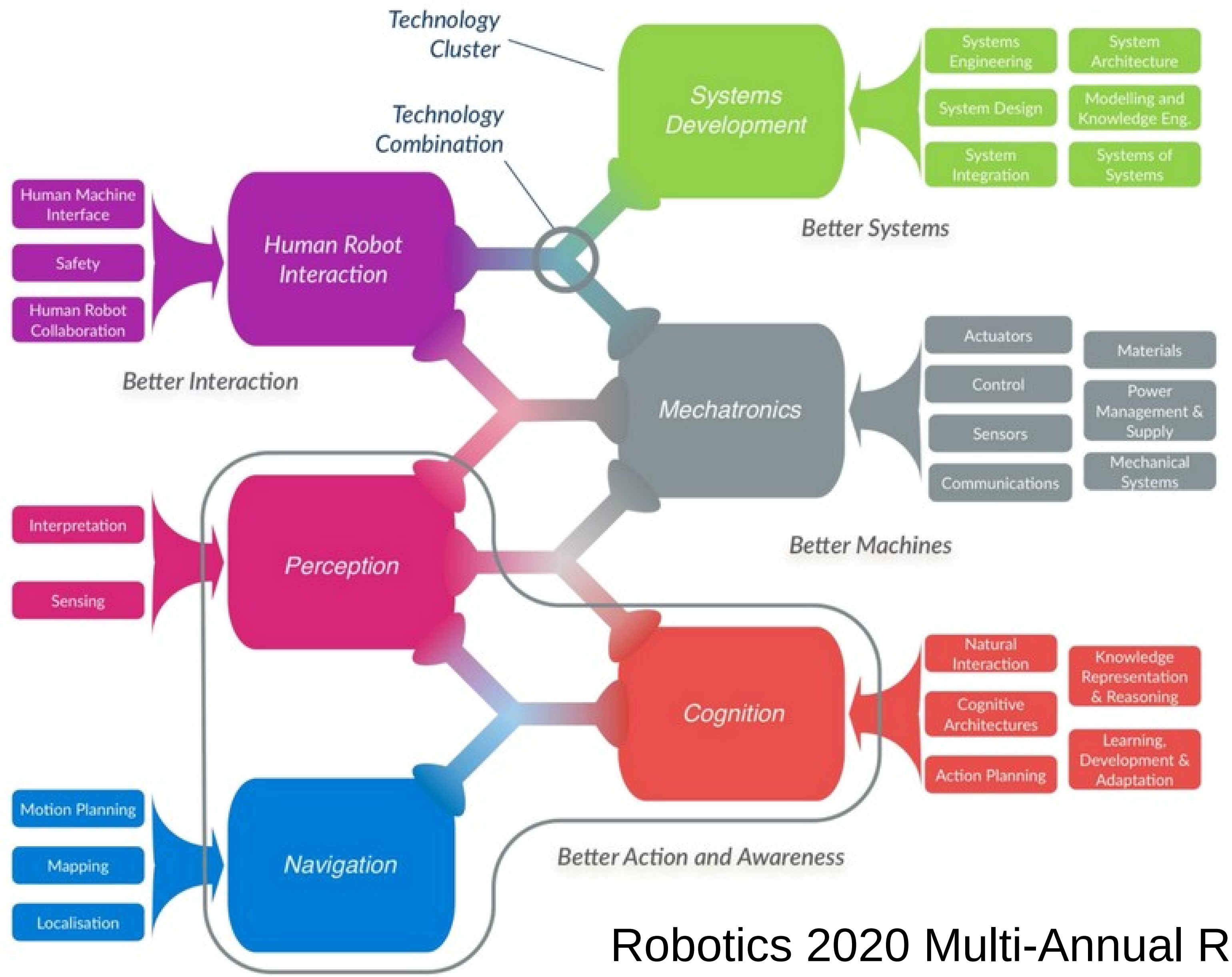
3D: Dirty Dull Dangerous ?

Domains



Robotics 2020 Multi-Annual Roadmap

Technologies



Robotics 2020 Multi-Annual Roadmap

History

800 BC - Homer: walking tripods in the Iliad

350 BC - Aristotle envisions mechanisms that work by "obeying or anticipating the will of others"

1495 - Leonardo DaVinci designed a mechanical device that looked like an armored knight, which moved in human-like motions.

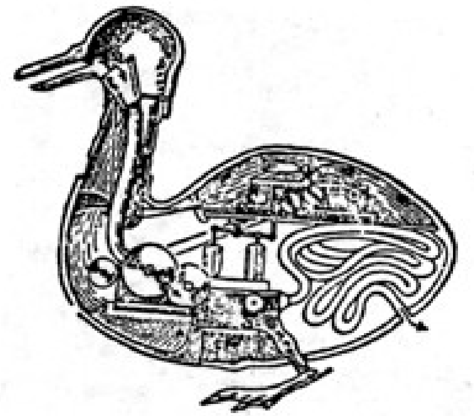
1640 - Descartes builds a female automaton which he calls “Ma fille Francine.”

1738 - Jacques de Vaucanson builds a mechanical duck made of more that 4,000 parts. The duck could quack, bathe, drink water, eat grain, digest it and void it.

1770 - Swiss clock makers and inventors Pierre Jaquet-Droz and his son Henri-Louis created three doll automata: write, play music, and draw pictures.

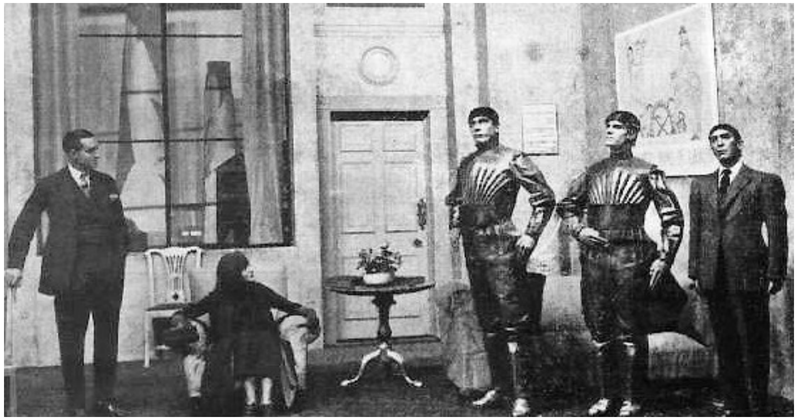
1898 - Tesla built and demonstrated a radio controlled robot boat at Madison Square Garden*.

1923 - Karel Capek coins the term *robot* in his play *Rossum’s Universal Robots (R.U.R).* *Robot* “might come” from the Czech word *robota*, which means “servitude, forced labor.”



Wikipedia

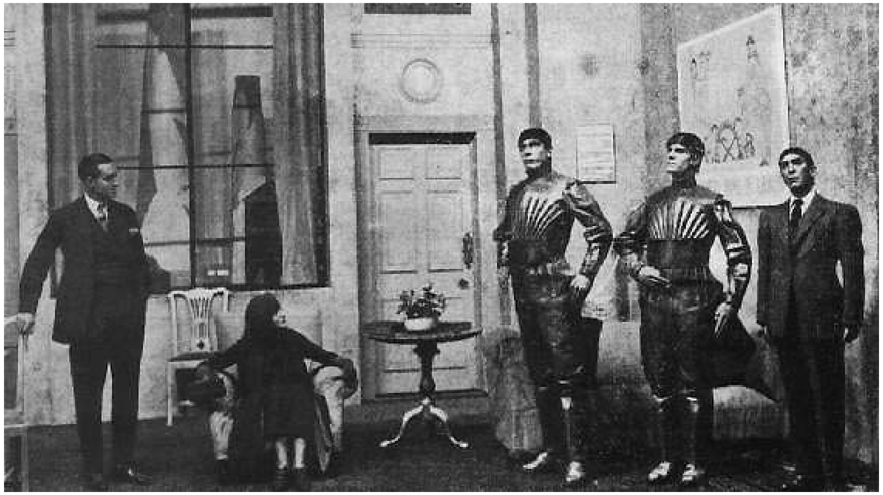
Wikipedia



Rossum’s Universal Robots (R.U.R)

Adapted from Martin P. Aalund

Robotlar, orijin, bugün

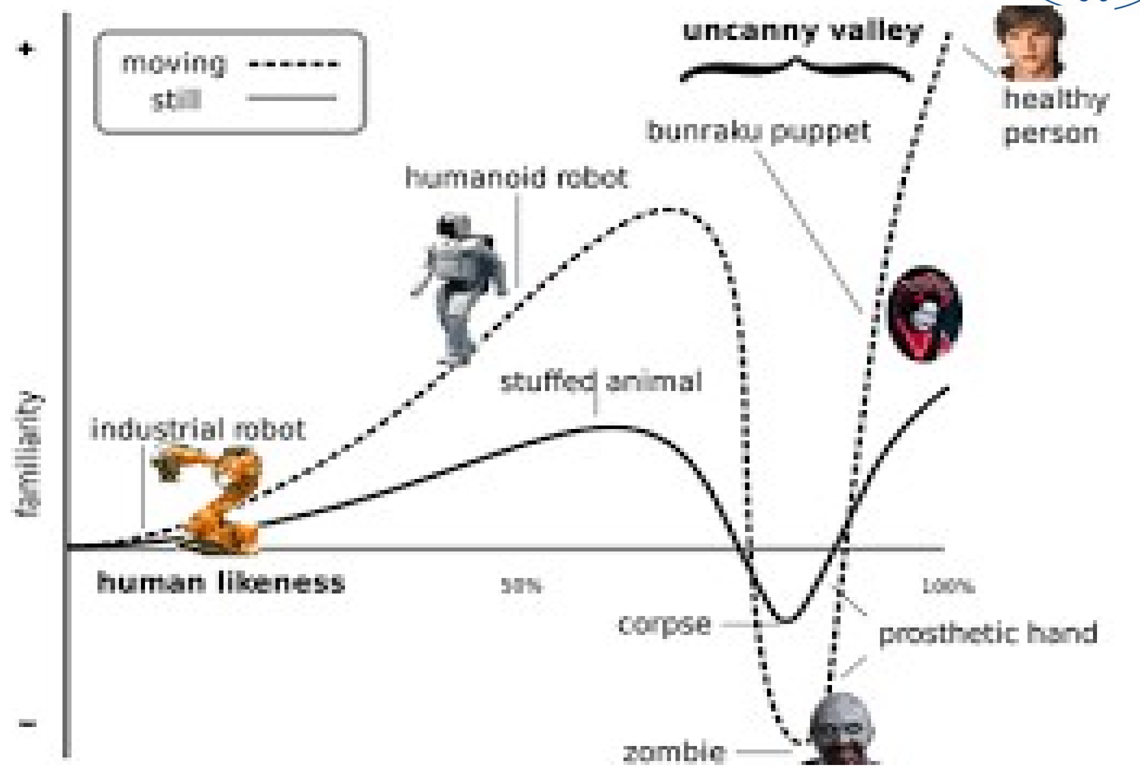


- Karel Capek’s play, Prague, 1921
- *Robota:* forced-labor

- Hiroshi Ishiguro’s play, Osaka, 2010
- The real robot plays an android role.

Robotlar, orijin, bugün

Prof. Hiroshi Ishiguro



History

1948 - Grey Walter's self-recharging Tortoise

Adapted from Martin P. Aalund

History

1948 - Grey Walter's self-recharging Tortoise

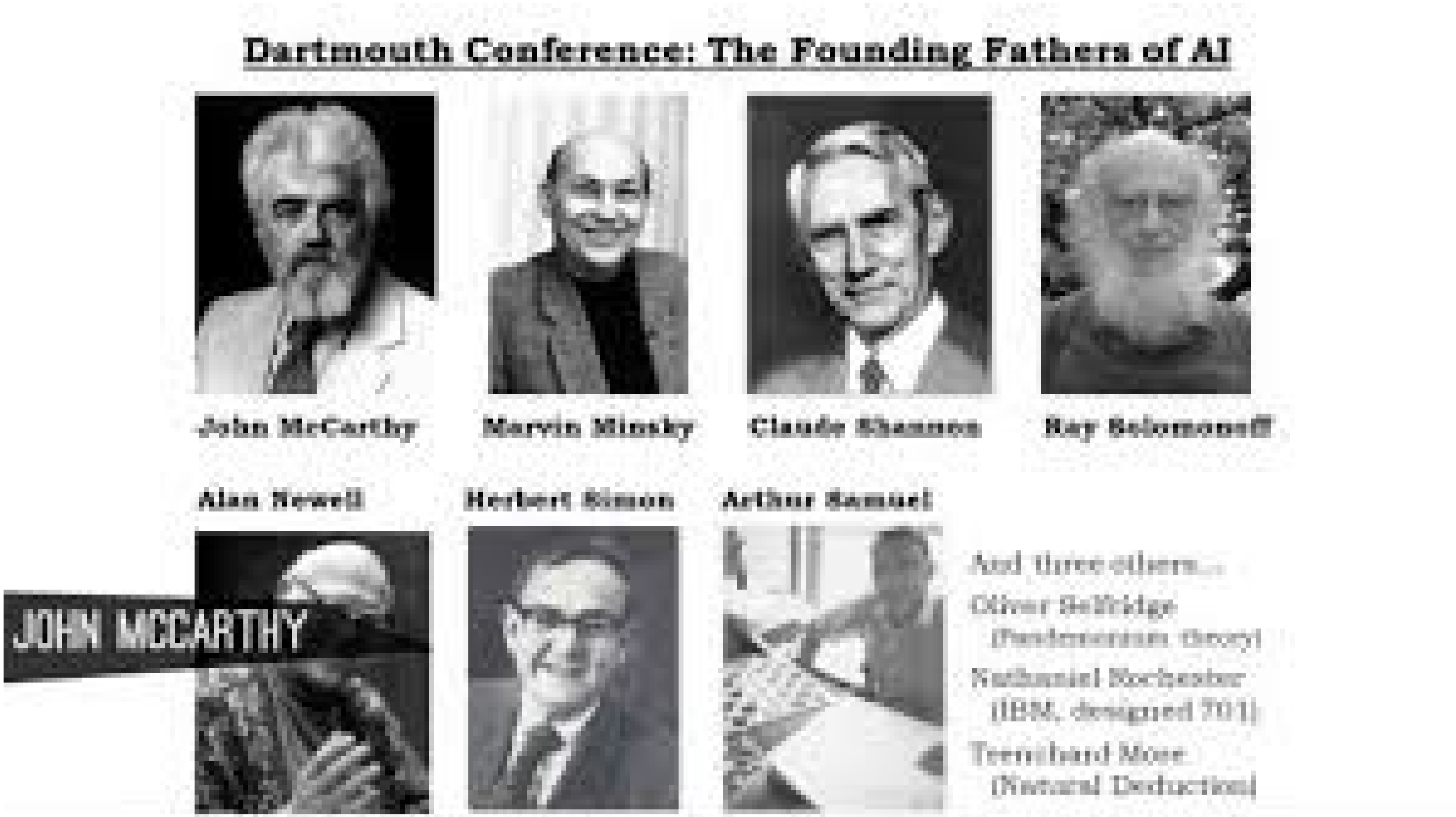
https://www.youtube.com/watch?v=lLULRlmXkKo

Adapted from Martin P. Aalund

History

1948 - Grey Walter's self-recharging Tortoise

1956 - A new discipline is born: A.I. John McCarthy, Marvin Minsky, Nat Rochester, and Claude Shannon organized ‘The Dartmouth Summer Research Project on Artificial Intelligence’ at Dartmouth College. This was the first use of the term ‘artificial intelligence.’



Adapted from Martin P. Aalund

History

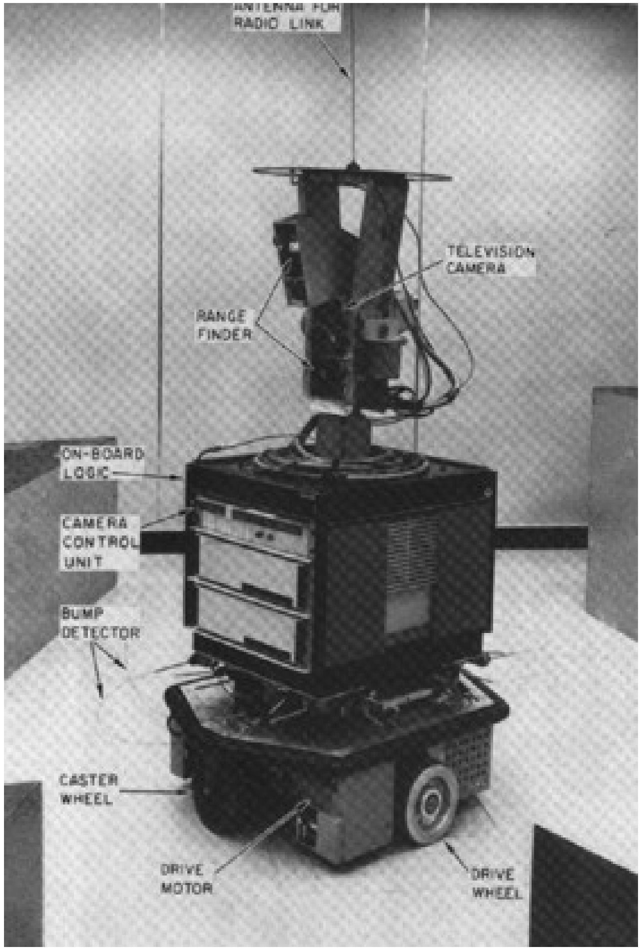
1956 - A new discipline is born: A.I. John McCarthy, Marvin Minsky, Nat Rochester, and Claude Shannon organized ‘The Dartmouth Summer Research Project on Artificial Intelligence’ at Dartmouth College. This was the first use of the term ‘artificial intelligence.’

Cognitive Science in 1950's

- Turing, Alan M. "On computable numbers, with an application to the Entscheidungsproblem." Proceedings of the London mathematical society 2.1 (**1937**): 230-265.
- McCulloch, W. S., & Pitts, W. (**1943**). A logical calculus of the ideas immanent in nervous activity. The bulletin of mathematical biophysics, 5(4), 115-133.
- Lettvin, J. Y., Maturana, H. R., McCulloch, W. S., & Pitts, W. H. (**1959**). What the frog's eye tells the frog's brain. Proceedings of the IRE, 47(11), 1940-1951.
- Hubel, David H., and Torsten N. Wiesel. "Receptive fields of single neurones in the cat's striate cortex." The Journal of physiology 148.3 (**1959**): 574-591.
- Miller, G. A. (**1956**). The magical number seven, plus or minus two: Some limits on our capacity for processing information. Psychological review, 63(2), 81.
- Newell, Allen, and Herbert Simon. "The logic theory machine--A complex information processing system." IRE Transactions on information theory 2.3 (**1956**): 61-79.
- Chomsky, Noam. "Three models for the description of language." IRE Transactions on information theory 2.3 (**1956**): 113-124.
- Von Neumann, John. **1958** The computer and the brain. Yale University Press,.
- Putnam, H. **1960**. "Minds and Machines." InS. Hook, ed., Dimensions of Mind. New York: New York University Press.
- Marr, D. (**1982**) Vision: A Computational Investigation info the Human Representation and Processing of Visual Information. San Francisco: W. H. Freeman.

History

1960 - Shakey is made at Stanford Research Institute International. It contained a television camera, range finder, on-board logic, bump sensors, camera control unit, and an antenna for a radio link.

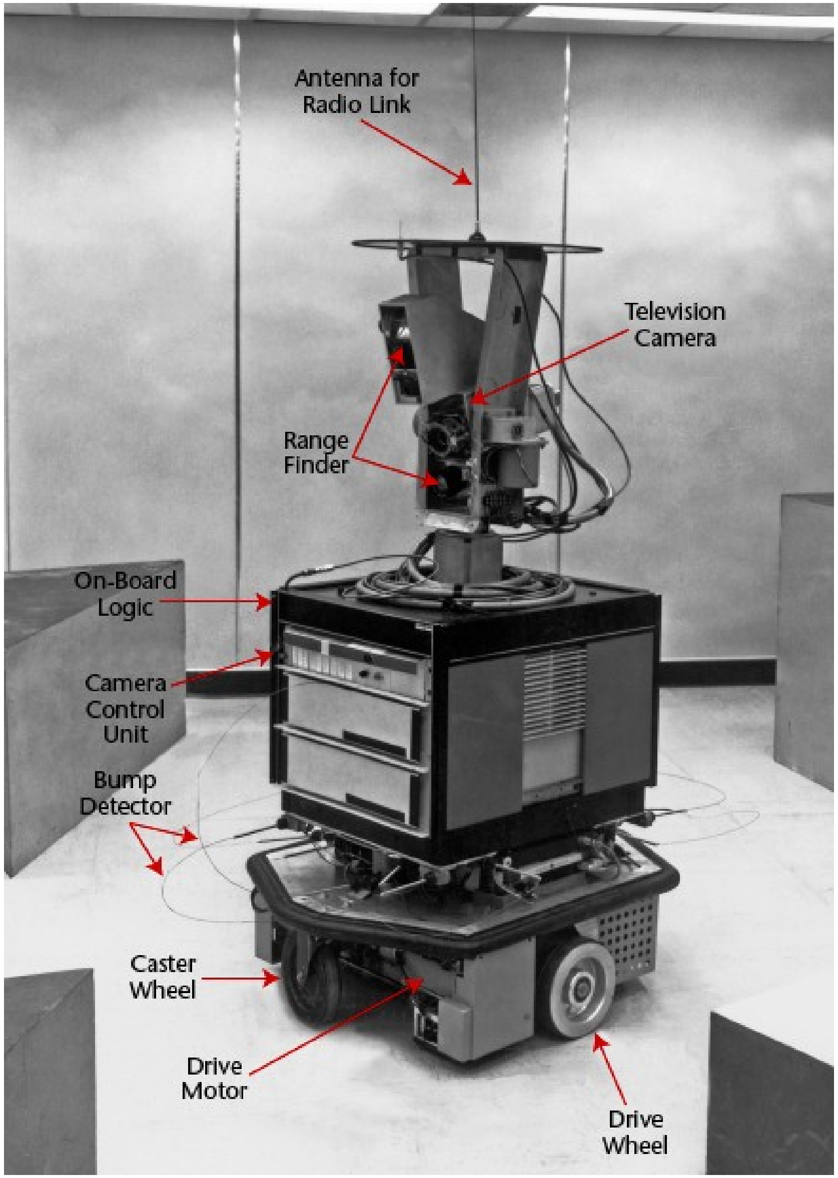


Shakey: https://www.youtube.com/watch?v=GmU7SimFkpU

Adapted from Martin P. Aalund

SHAKEY (1970)

- At SRI (Stanford Research Institute)
- State-of-the-art machine vision used to process visual information
- Used classical planner (STRIPS)
- Shakey had
  - A TV camera,
  - A triangulating range finder,
  - Bump sensors,
  - Was connected to DEC PDP-10 and PDP-15 computers via radio and video links.



https://www.youtube.com/watch?v=7bsEN8mwUB8
From 2:00

Planning

- Looking ahead, searching for what to do next
- The goal is a state
- Entire state space is enumerated and searched from current state to goal state
- Different paths are tried
- Optimal path is the one we want to use

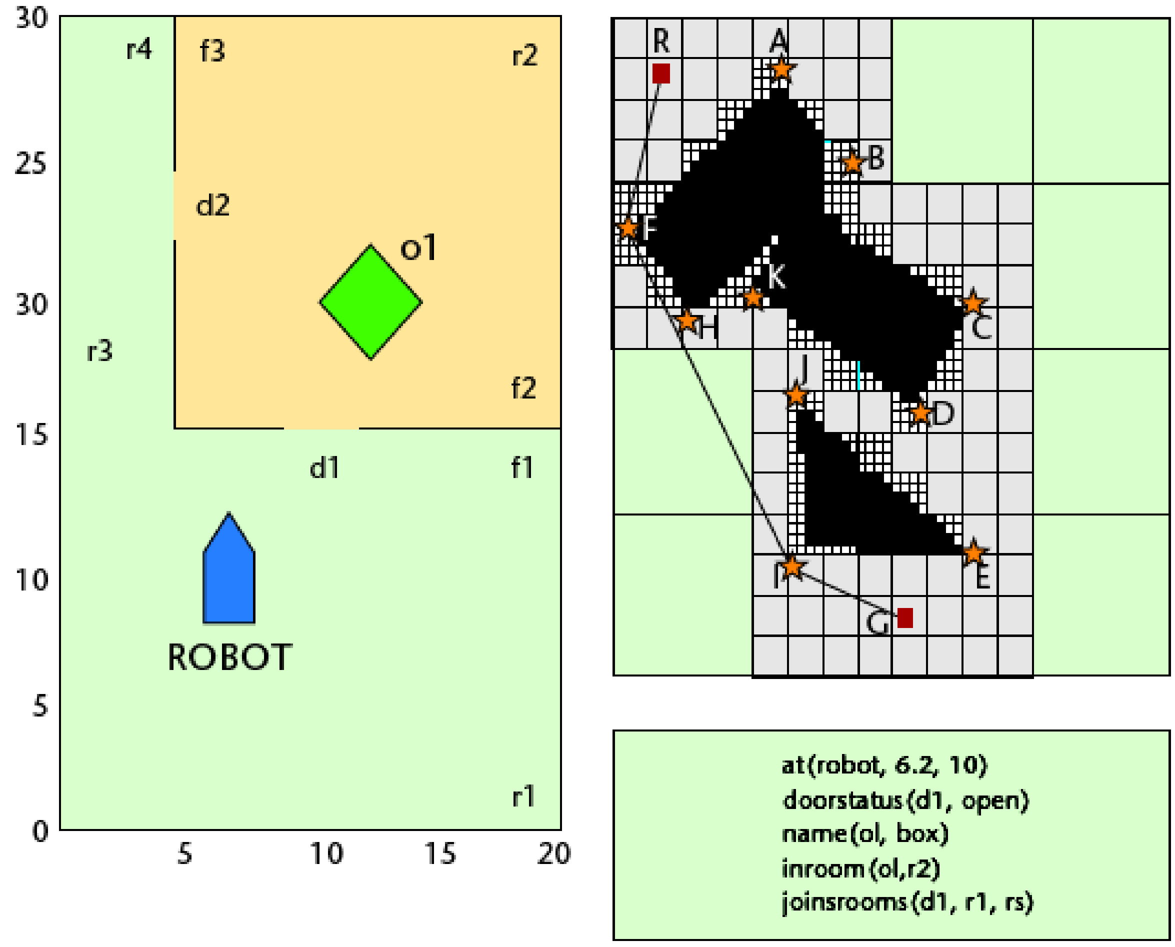


Figure 4. Predicate Calculus Model Fragment with Plan View of World and Grid Model

Planning

- Looking ahead, searching for what to do next
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- Entire state space is enumerated and searched, from current state to goal state
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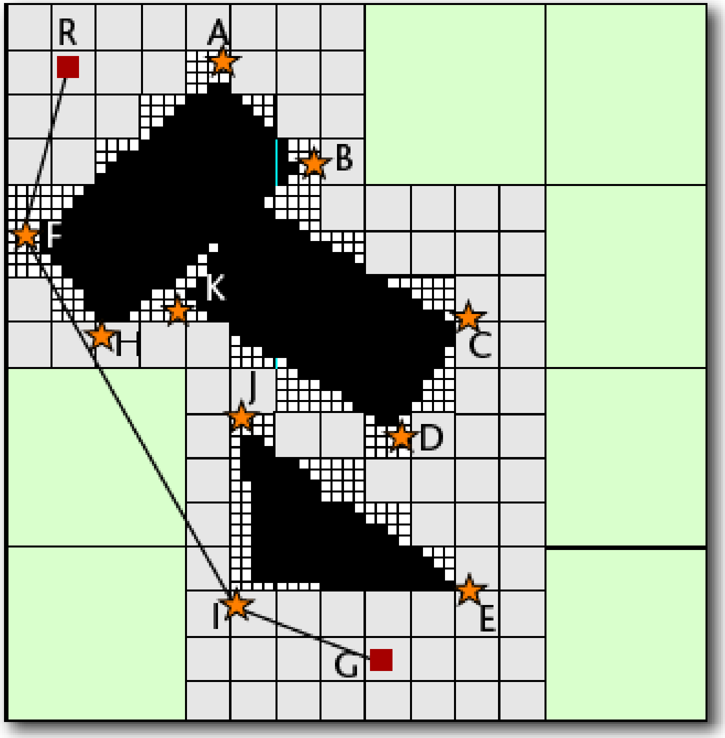
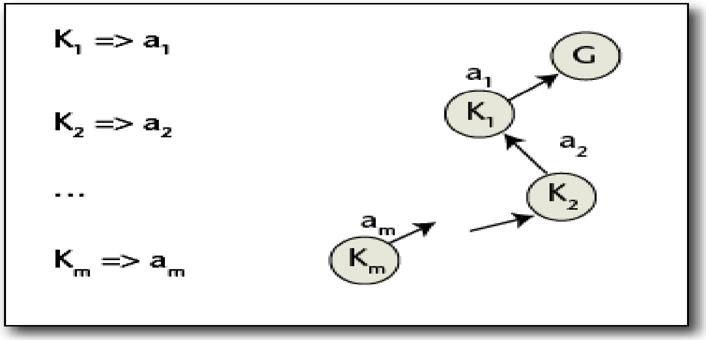


Figure 13. Shakey's Adaptive Grid Model.



Planning

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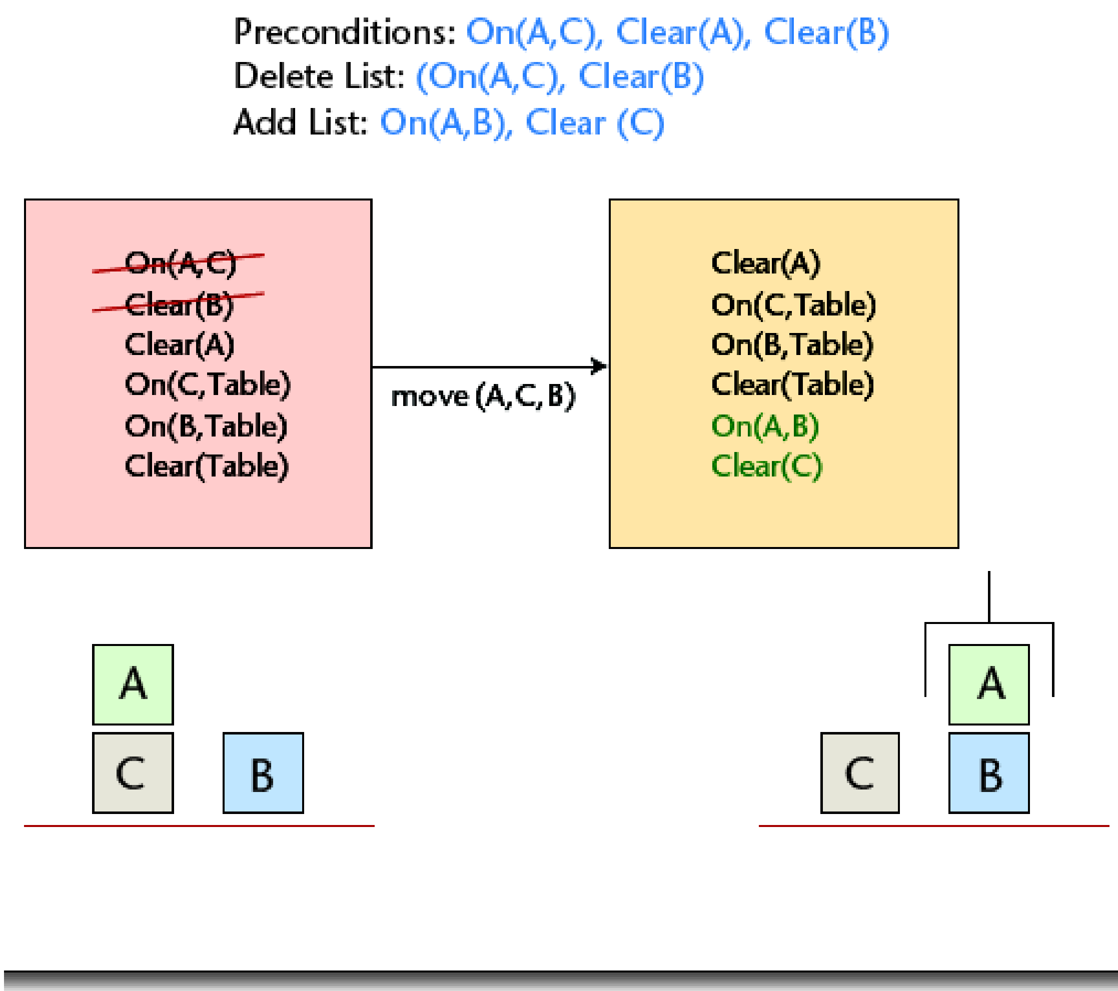
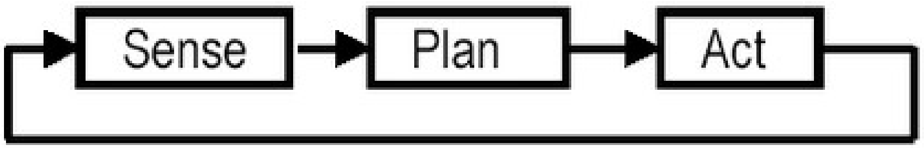


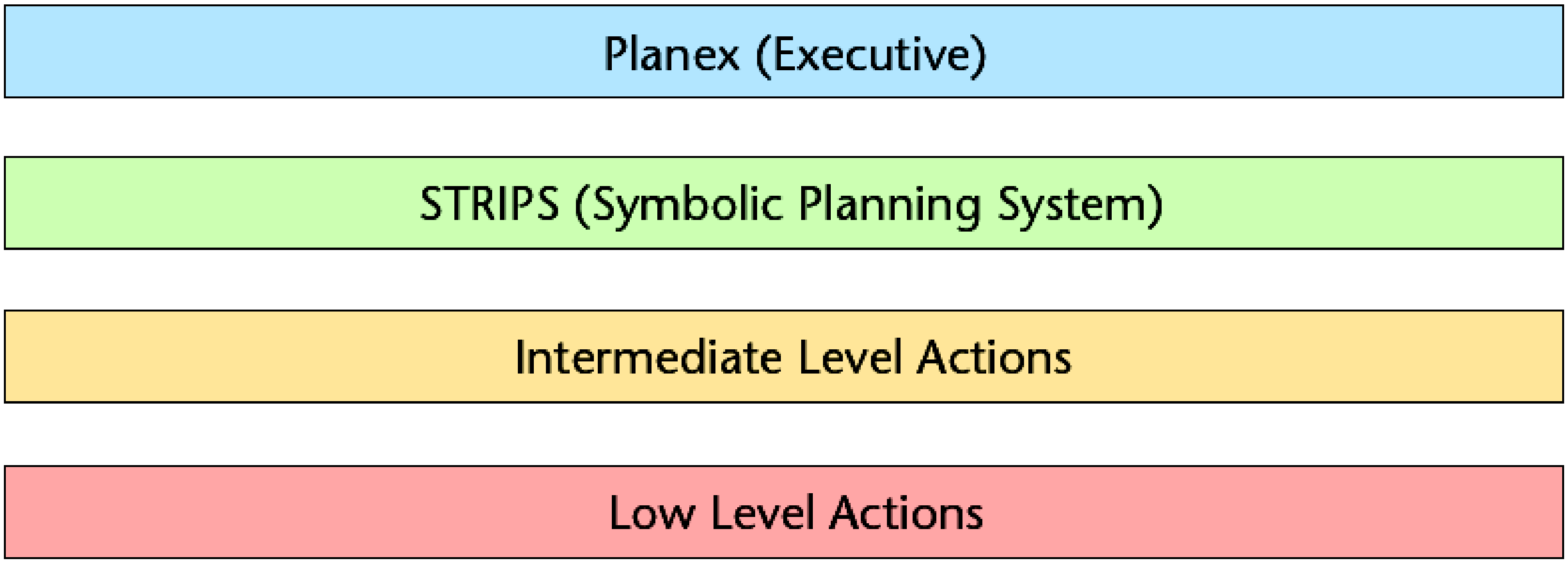
Figure 14. Application of a STRIPS Rule.

SPA

- Planner-based architecture
- Involves 3 steps:
  1. Sensing (S)
  2. Planning (P)
  3. Acting (A)



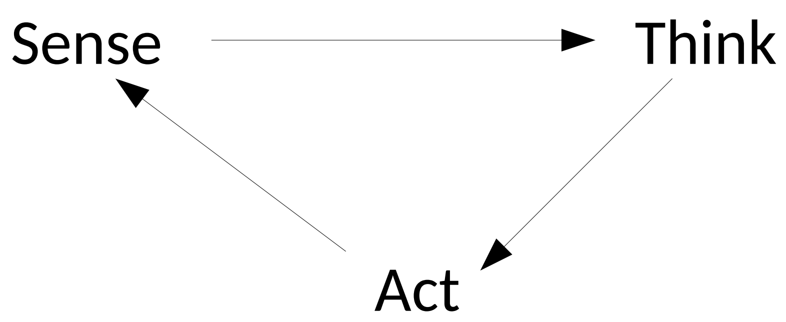
- SPA has serious drawbacks…



The robot control loop

Speech, Vision
Acceleration, Temperature
Position ,Distance
Touch, Force
Magnetic field ,Light
Sound ,PositionSense

Task planning
Plan Classification
Learn
Process data
Path planning
Motion planning
Reasoning

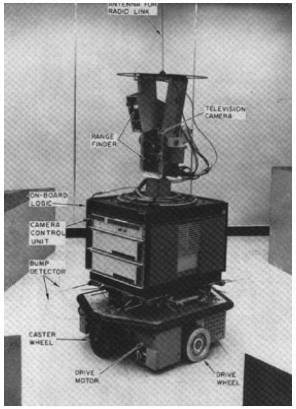


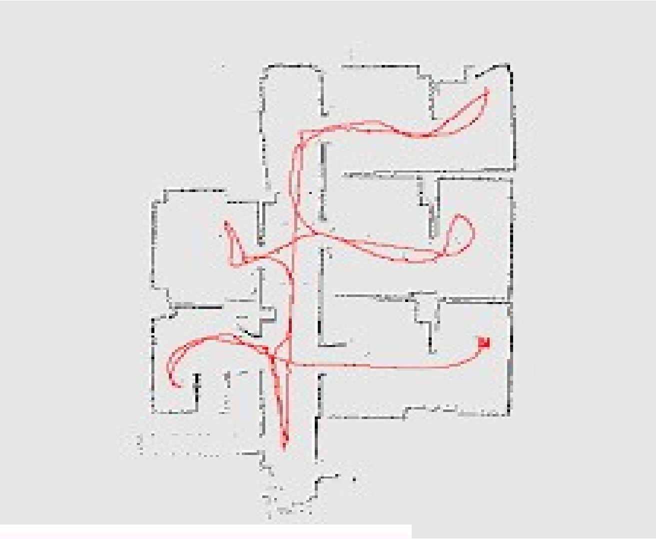
Output information,
Move, Speech
Text, Visuals, Wheels, Legs
Arms, Tracks

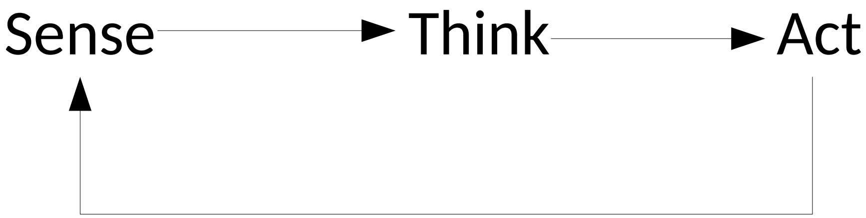
Source: https://www.slideshare.net/MelakuBayih1/chapter-5-57421516

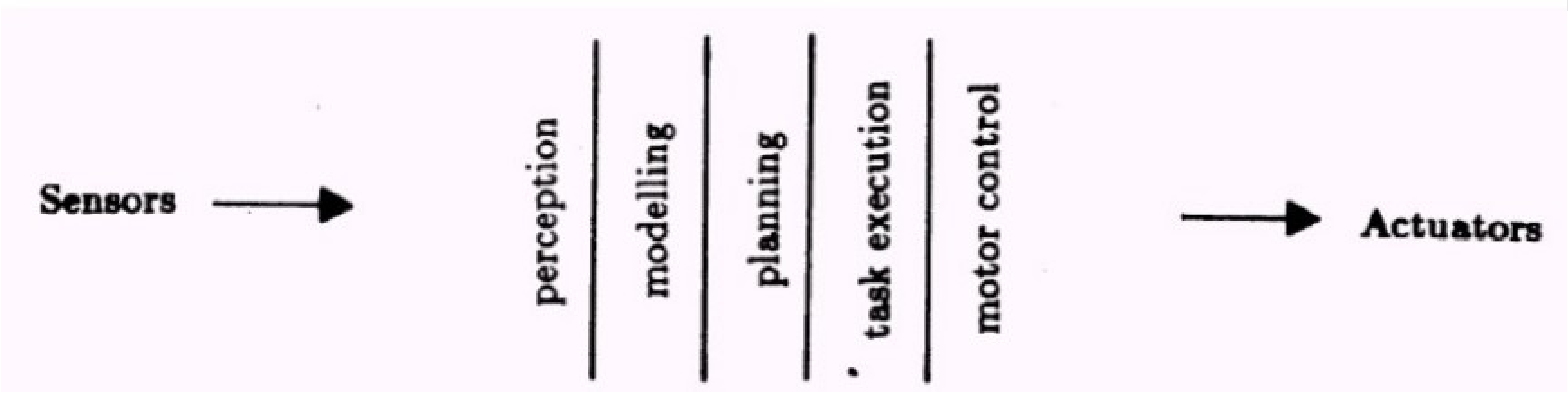
The robot control loop

- Deliberative paradigm



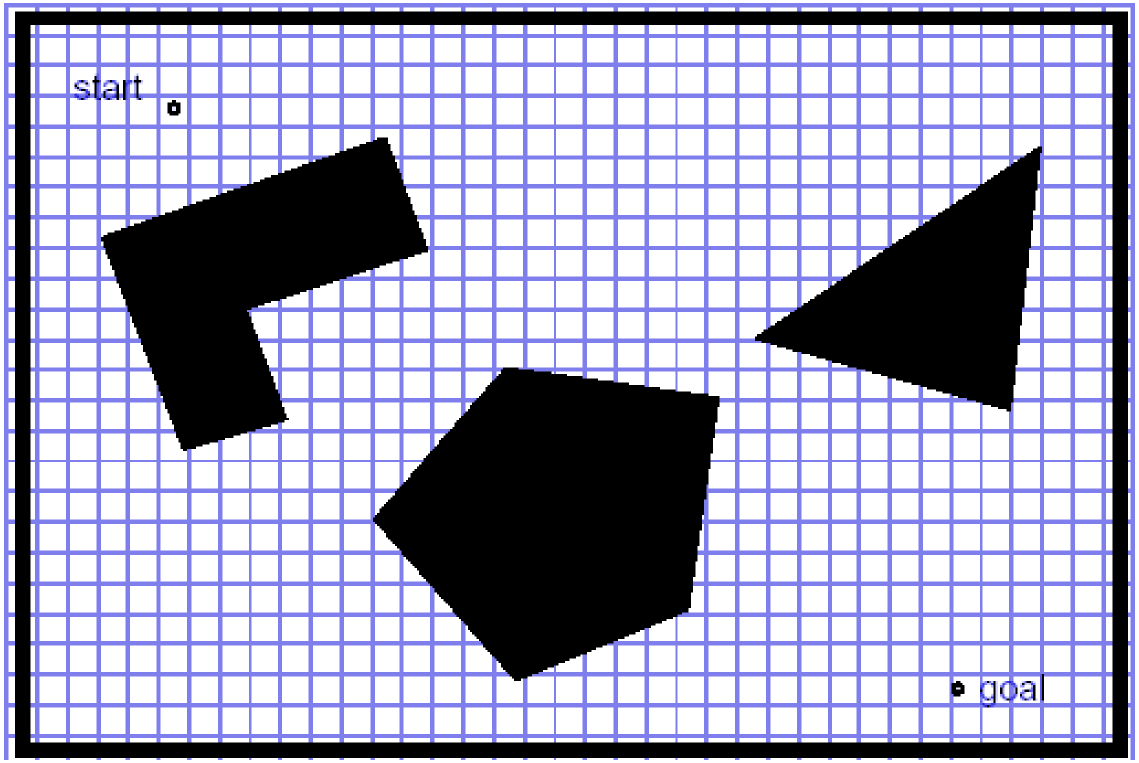






A Robot's Navigation Problems

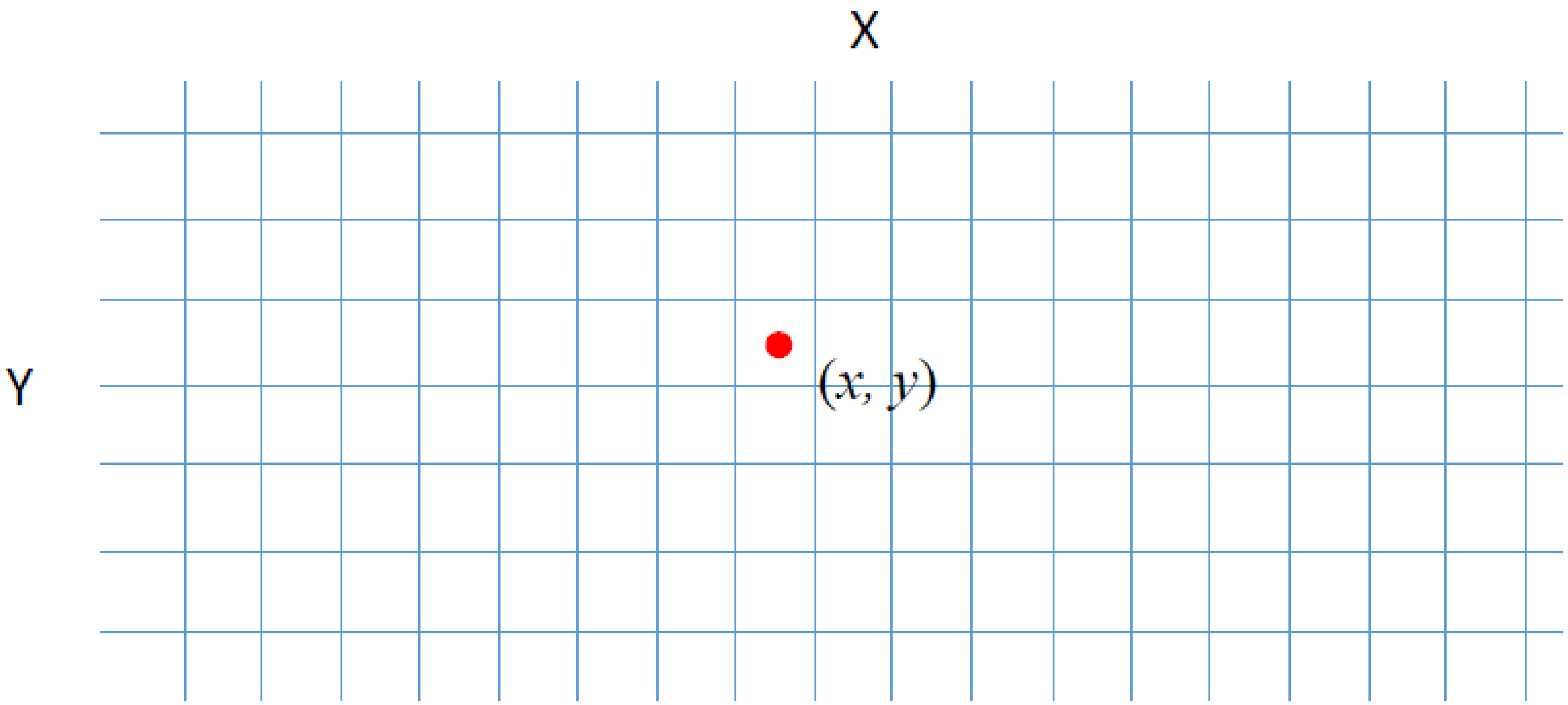
- Where am I? *Localization*
- Where have I been? *Map making*
- Where am I going? *Mission planning*
- What's the best way there? *Path planning*



Types of Map (1) – Metric map

41.0854156,29.042663

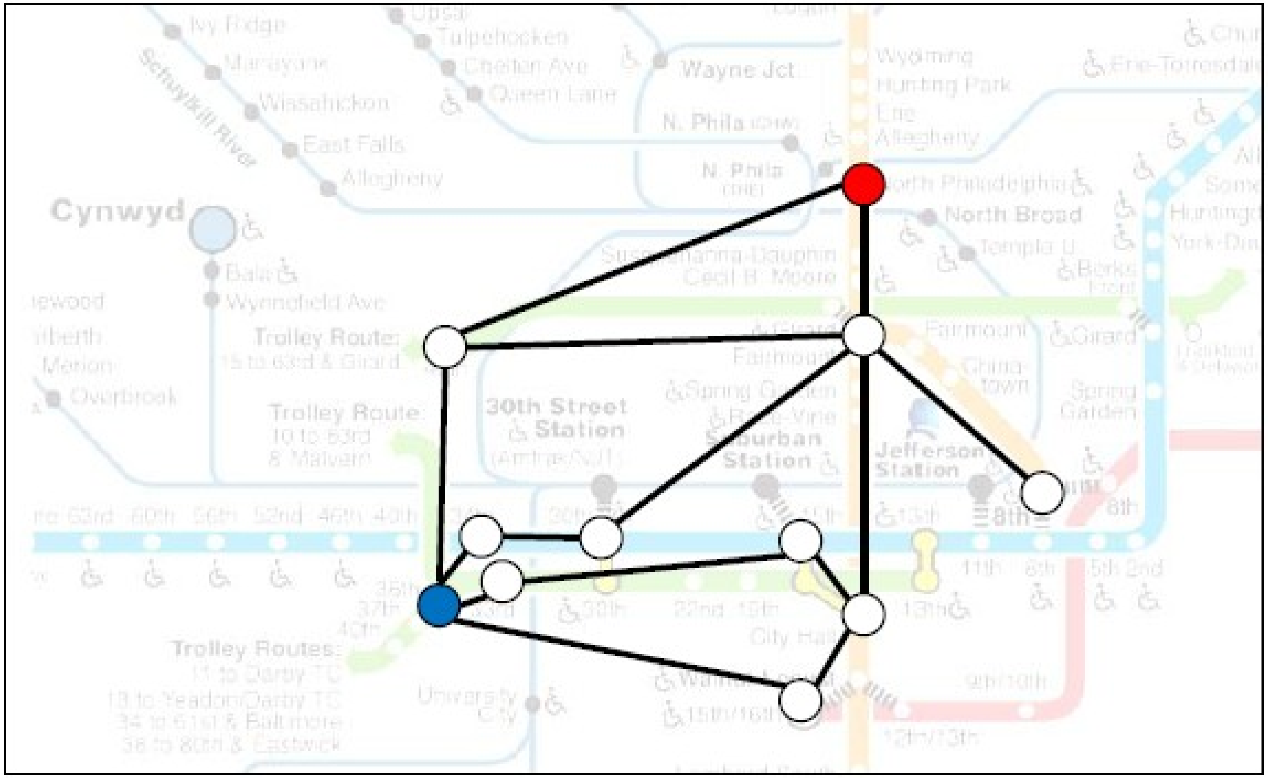
Types of Map (1) — Metric map



A location is represented as a coordinate.

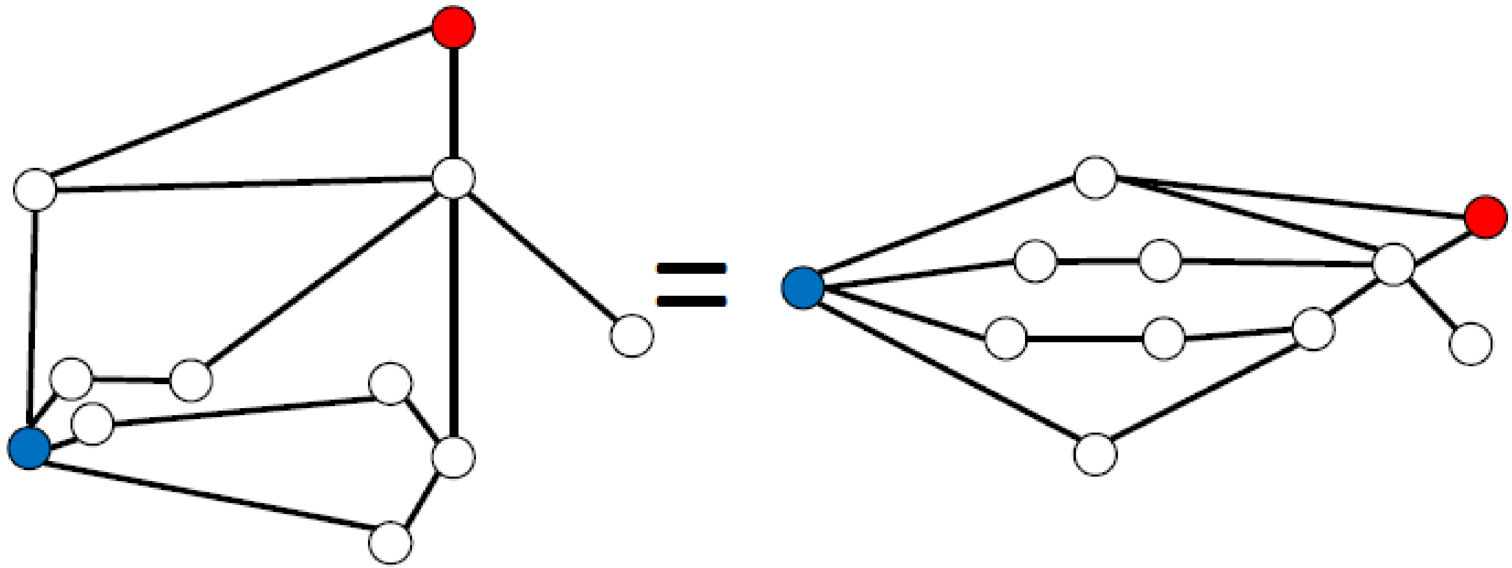
Types of Map (2) – Topological map

Types of Map (2) – Topological map



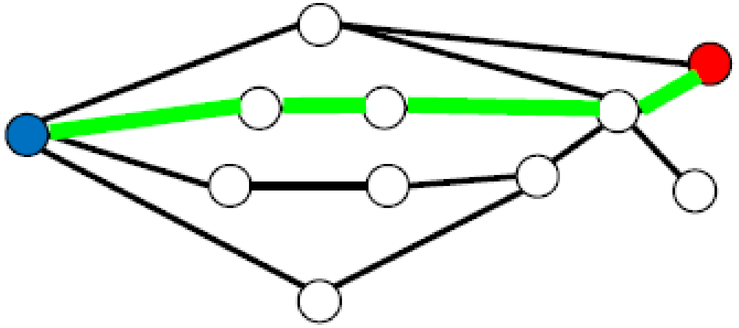
Locations are represented as nodes and their connectivity as arcs.

Types of Map (2) – Topological map



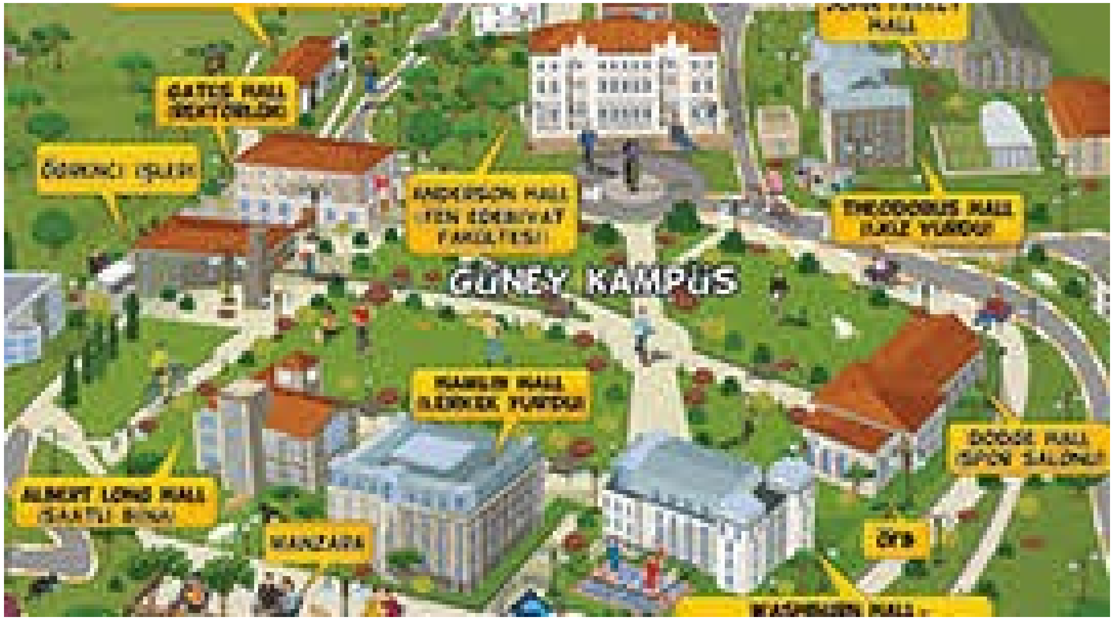
Only the connectivity between nodes matter.

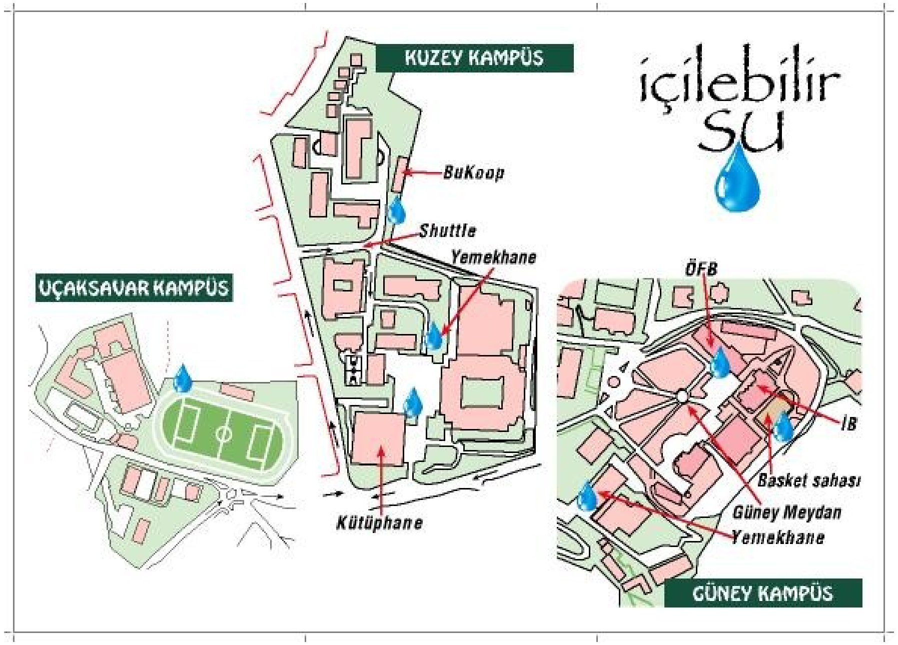
Types of Map (2) – Topological map



Graph representation is useful for path planning.

Types of Map (3) – Semantic map



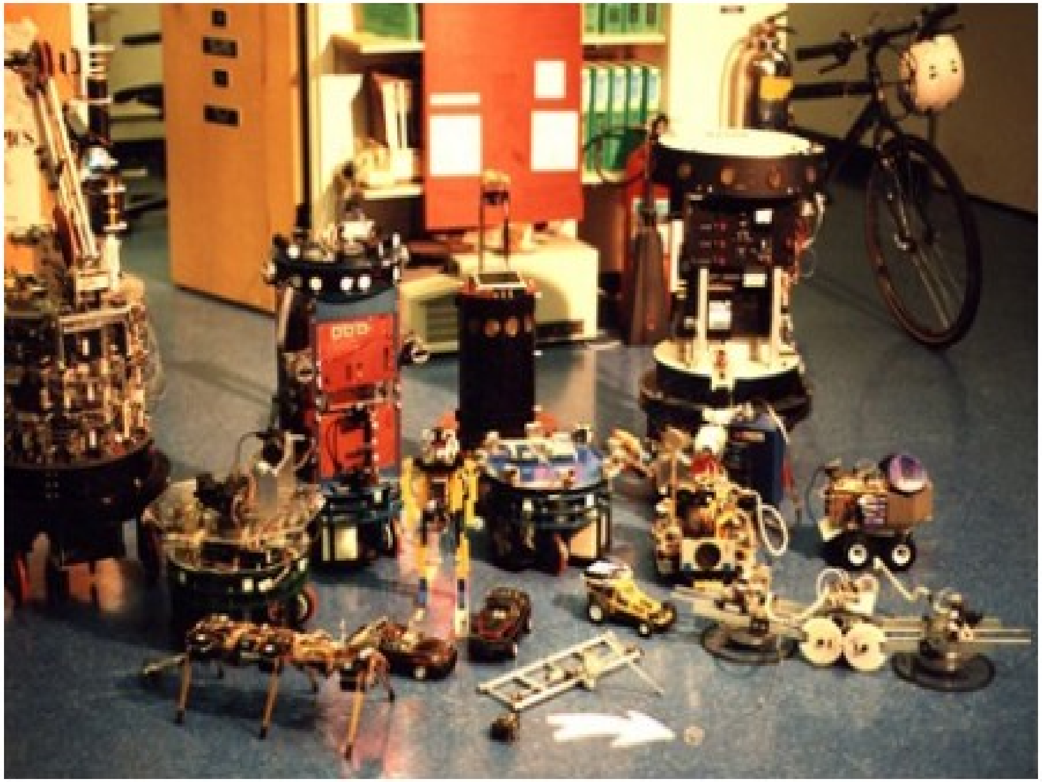


Semantic map is a map with labels.

The robot control loop

- Reactive paradigm

Sense ⟷ Act



Rodney Brooks

Emergent Behavior

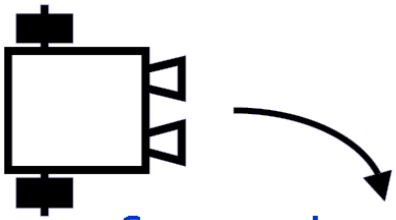
- Important but not well-understood phenomenon
- Often found in behavior-based robotics
- Robot behaviors “emerge” from
  - Interactions of rules
  - Interactions of behaviors
  - Interactions of either with environment

Why?

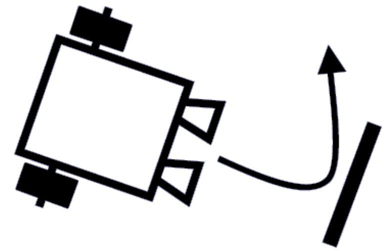
- Sum is greater than the parts
- Emergent behavior is more than the controller that produces it

Example: Wall Following

coded behaviors



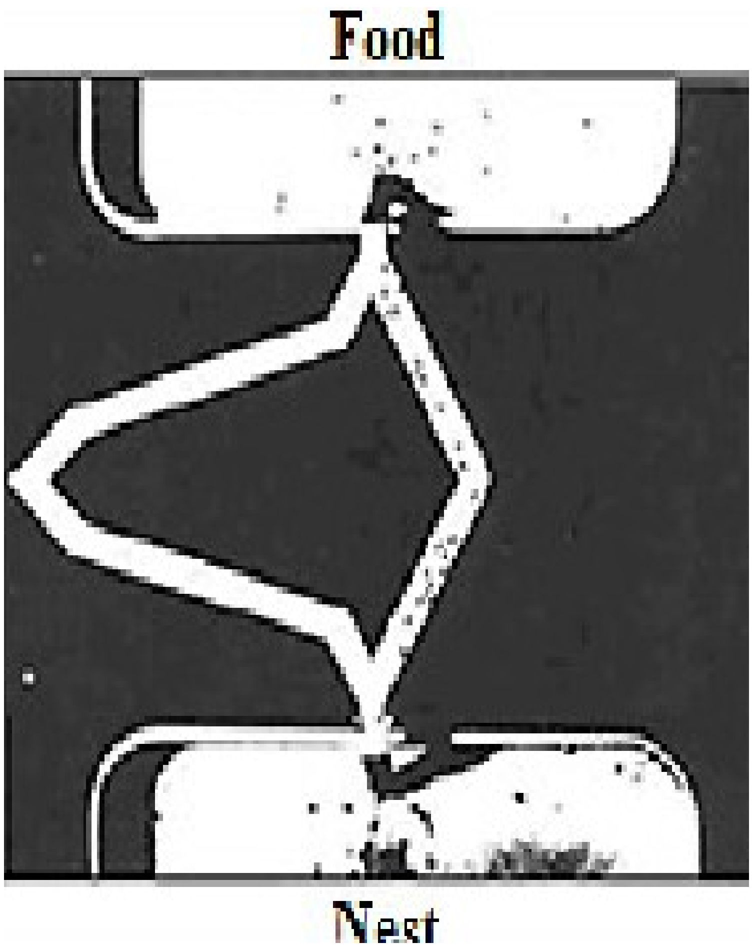
forward motion,
with slight turn right

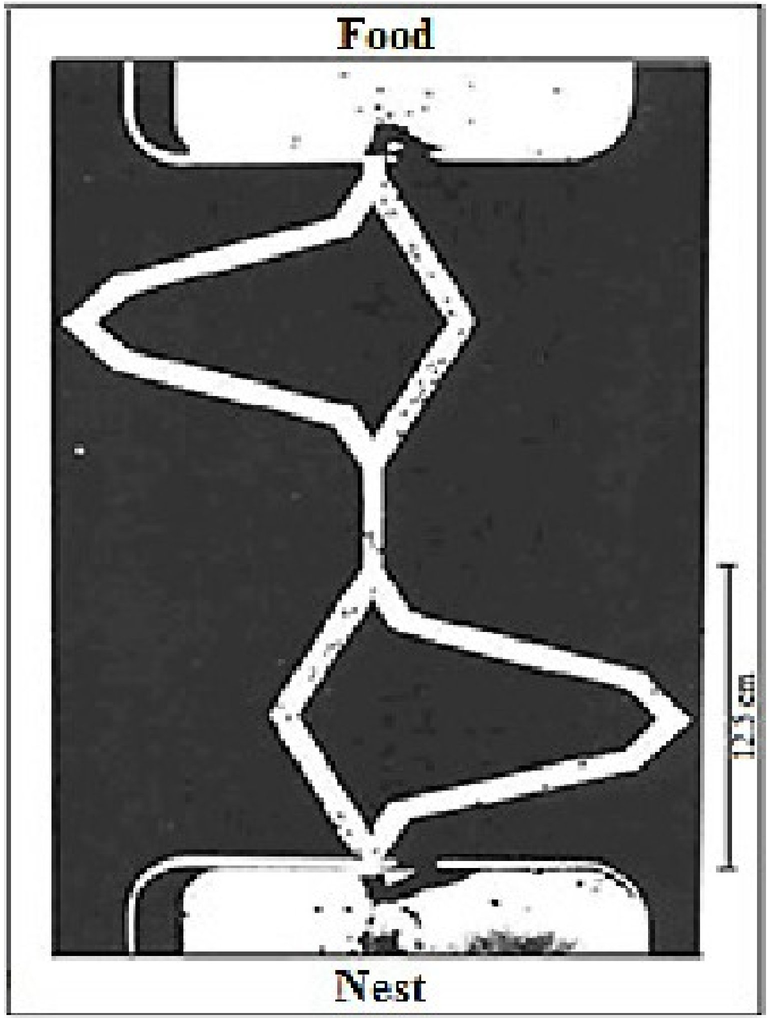


obstacle
avoidance

Emergent Behavior

Emergent Behavior

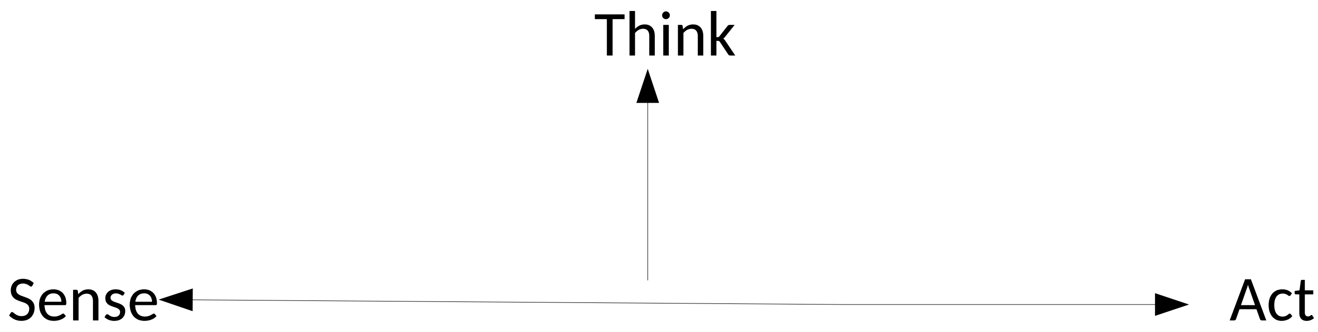




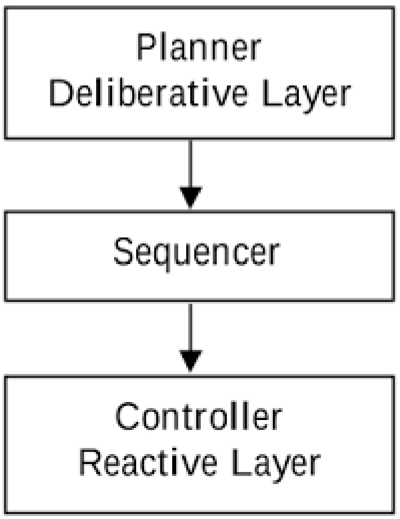
https://www.youtube.com/watch?v=oBhv4pKksgU

The robot control loop

- Hybrid paradigm

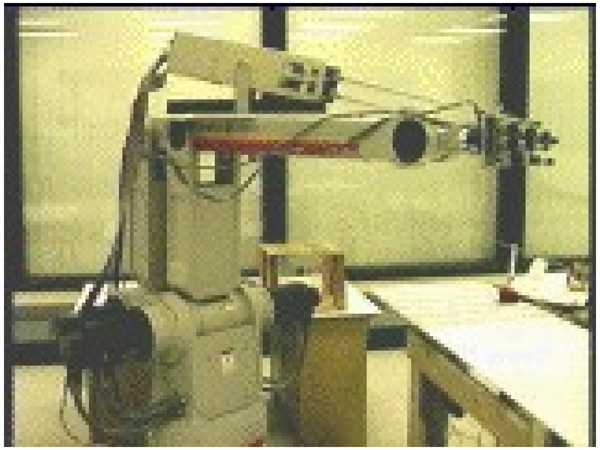


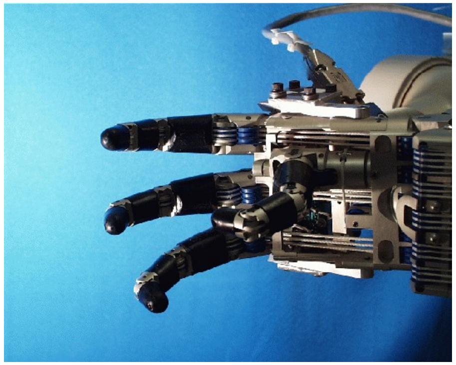
- 3-layered architectures

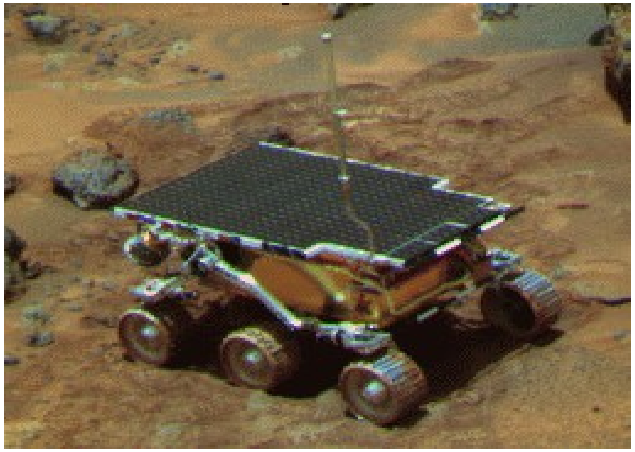


Robot Classes

- *Manipulators*: robotic arms. These are most commonly found in industrial settings.
- *Mobile Robots*: unmanned vehicles capable of locomotion.
  - Walking, climbing, swimming, flying







Robot Components

Body: Links, joints, other structural element of the robot

End Effector: The part that is connected to the last joint of a manipulator.

Actuators: Muscles of the manipulators (servomotor, stepper motor, pneumatic and hydraulic cylinder.

Sensors: To collect information about the internal state of the robot or to communicate with the outside environment.

Controller: It controls and coordinates the motion of the actuators.

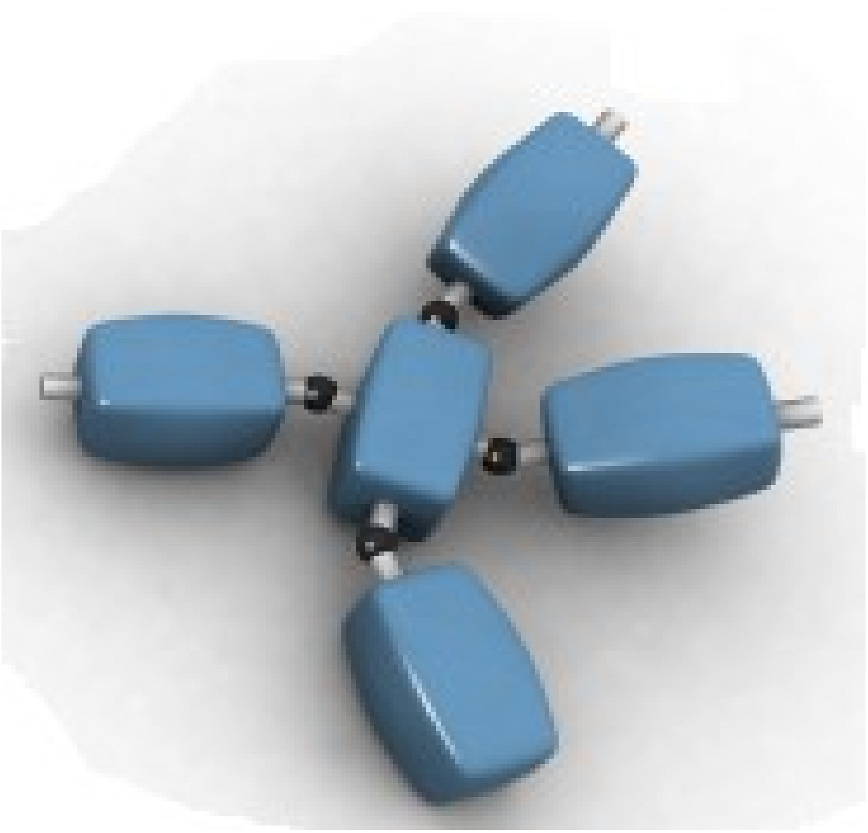
Processor: The brain of the robot. It calculates the motions and the velocity of the robot's joints, etc.

Software: Operating system, robotic software and the collection of routines.

Source: https://www.slideshare.net/AmeyaGandhi/basics-of-robotics

Robot::Body

- Typically defined as a graph of *links* and *joints*:

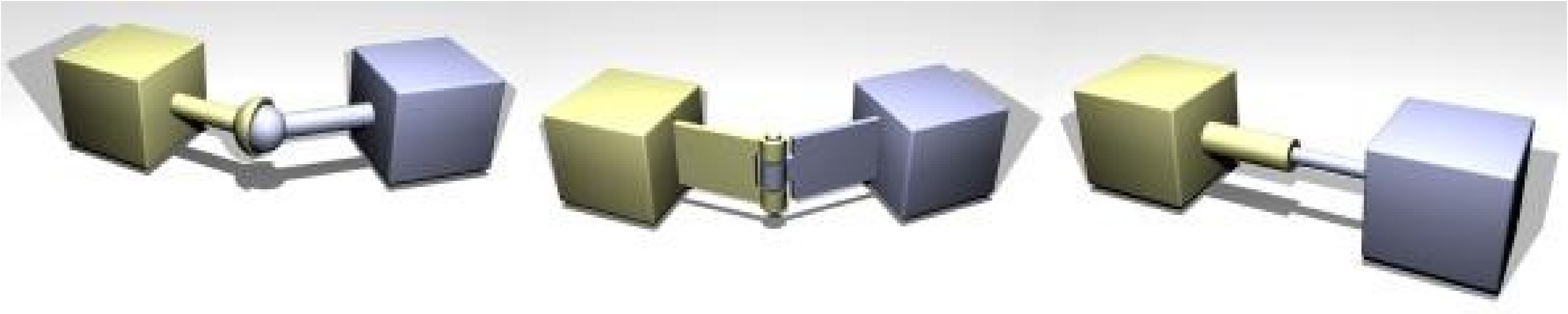


A link is a part, a shape with physical properties.

A joint is a constraint on the spatial relations of two or more links.

Source:https://www.slideshare.net/GarvitArya/introduction-to-robotics-52213326

Types of Joints



Respectively, a *ball joint*, which allows rotation around x, y, and z, a *hinge-revolute joint*, which allows rotation around z, and a *slider-prismatic joint*, which allows translation along x.

These are just a few examples…

Source:https://www.slideshare.net/GarvitArya/introduction-to-robotics-52213326

Degrees of Freedom

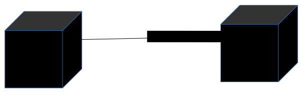
The degree of freedom (DOF) of a mechanical system is the number of independent parameters that define its configuration

2D

(x,y)

3D

(x,y,z)

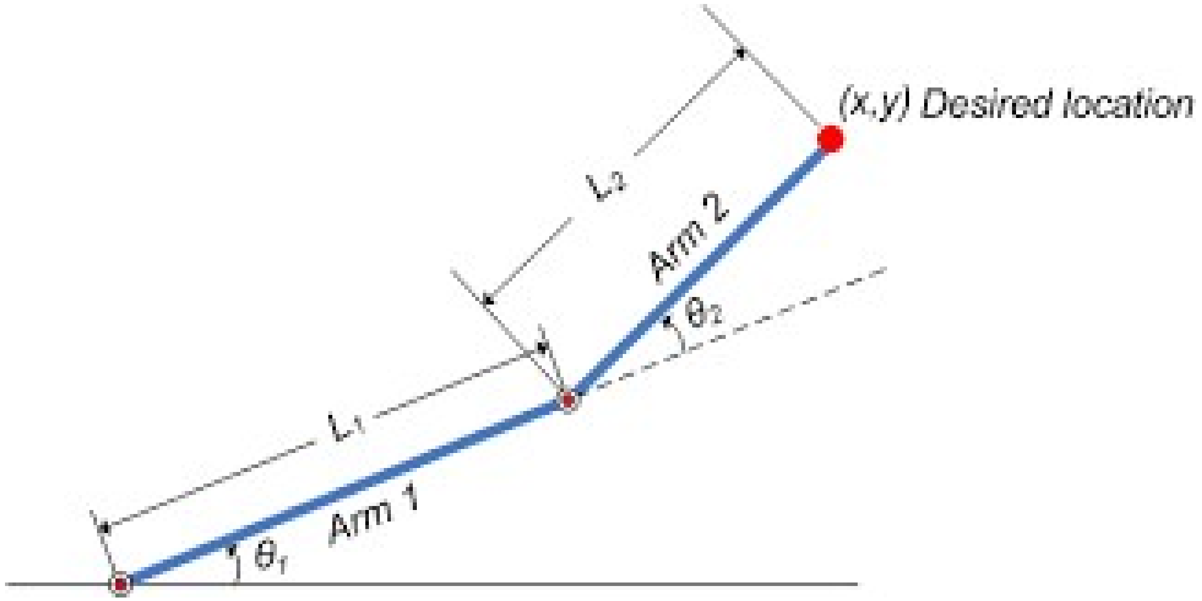


3D

?

Degrees of Freedom

- Joints constraint free movement, measured in “Degrees of Freedom” (DOFs).
- Joints reduce the number of DOFs by constraining some translations or rotations.
- Robots classified by total number of DOFs
- DOFs: Every joint or movable axis (including the arm).

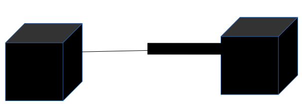


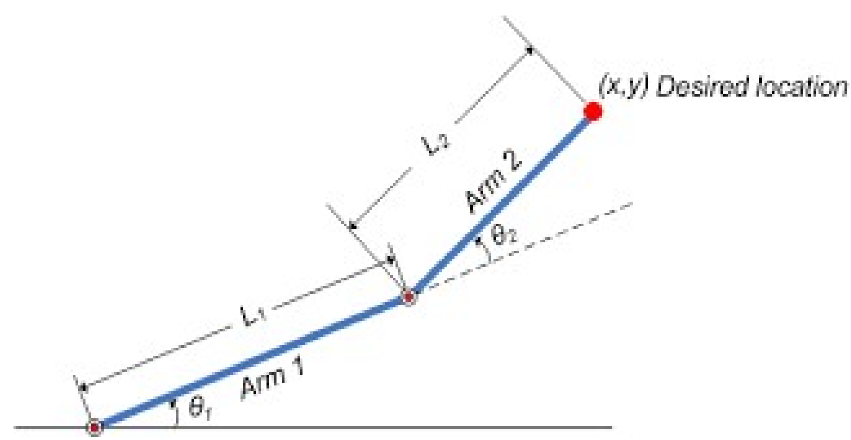
Source:https://www.slideshare.net/GarvitArya/introduction-to-robotics-52213326

Classification of Robot Arms:
Work Envelope Geometry

Kinematics of Robot Arms is defined as the ***Relationship*** between arm (link) parameters and the configuration (position and orientation) of the end-effector with respect to a reference point

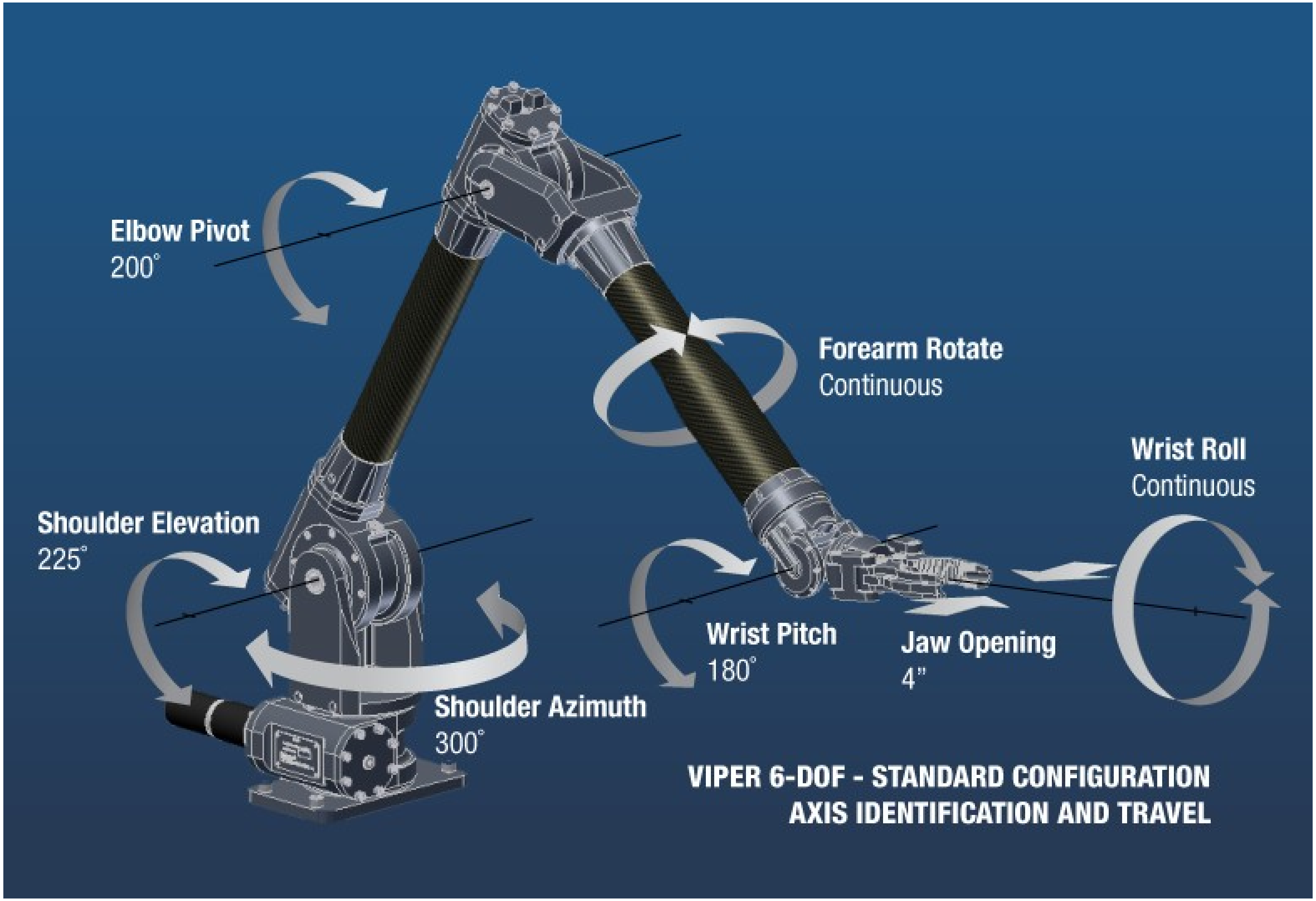
Kinematics is motion without forces or mass



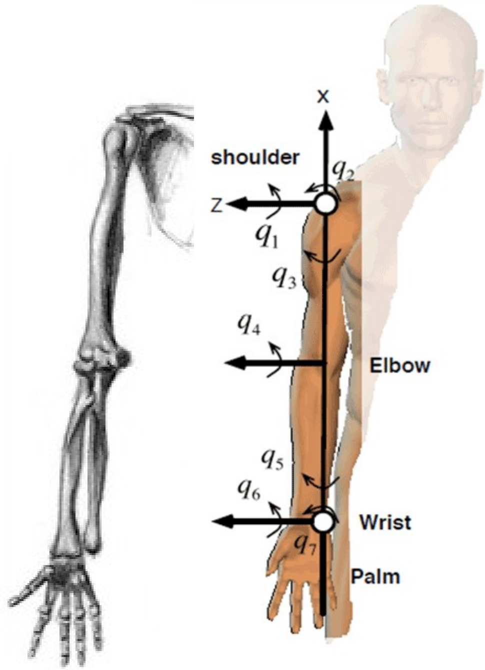


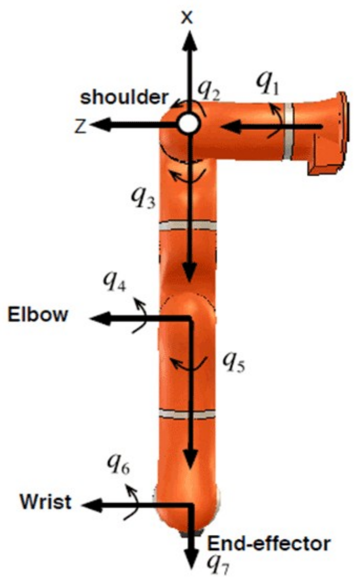
Adapted from: www.cs.ust.hk/~helens/comp322/lecture/Lecture-03.ppt

6-DOF Robot Arms



High-DOF Robot Arms





KUKA LWR

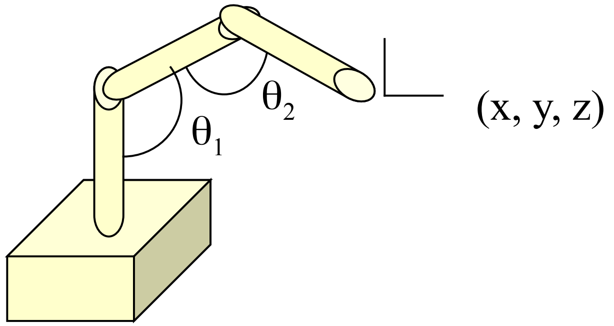
Baxter robot arm

Franka arm

Control?

Modeling the Robot Mechanism

- Forward kinematics describes how the robots joint angle configurations translate to locations in the world



$(\theta_1,\theta_2) \rightarrow (x,y,z)$

- Inverse kinematics computes the joint angle configuration necessary to reach a particular point in space.

$(x,y,z) \rightarrow (\theta_1,\theta_2)$

- Jacobians calculate how the speed and configuration of the actuators translate into velocity of the robot

$(\Delta x,\Delta y,\Delta z) \rightarrow (\Delta\theta_1,\Delta\theta_2)$

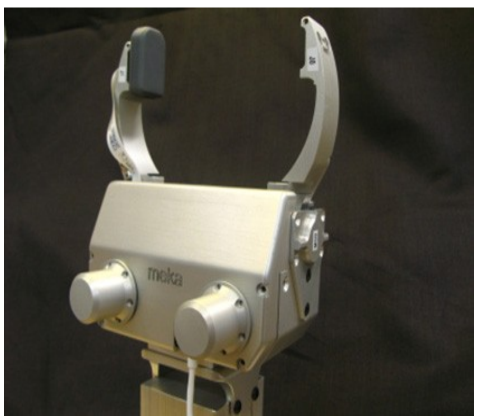
Adapted from: https://www.slideshare.net/ashishswain2/robotics-1-63951938

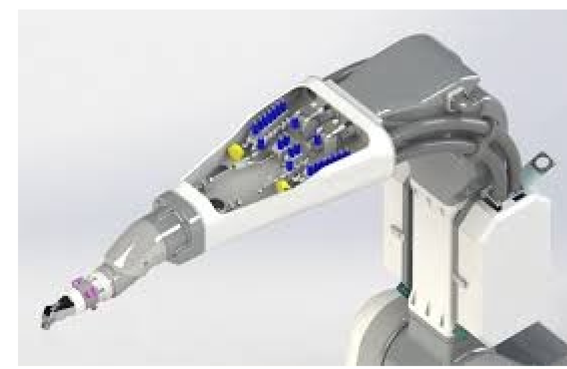
End Effectors

In robotics, an end effector is the device at the end of a robotic arm, designed to interact with the environment.

End effectors may consist of a gripper or a tool. The gripper can be of two fingers, three fingers or even five fingers.

Wikipedia



Robot::Actuators

- Actuators are the “muscles” of the robot.
- These can be electric motors, hydraulic systems, pneumatic systems, or any other system that can apply forces to the system.

https://www.slideshare.net/GarvitArya/introduction-to-robotics-52213326

Classification of Robot Arms: by Drive Technology

- **Hydraulic System**
- **Electric System**
  - AC motor, DC servo or stepper motor
  - for small robots
  - Advantages:
    - high accuracy
    - high repeatability
    - clean
  - Disadvantages:
    - less power, i.e. less payload
    - slower

Accuracy: how close a robot can position its payload to a given programmed point.

Repeatability: a measure of how close the robot returns to its previously established position on subsequent attempts.

Payload: the maximum load that the manipulator can handle (includes the weight of the gripper plus the weight of whatever the gripper carries).

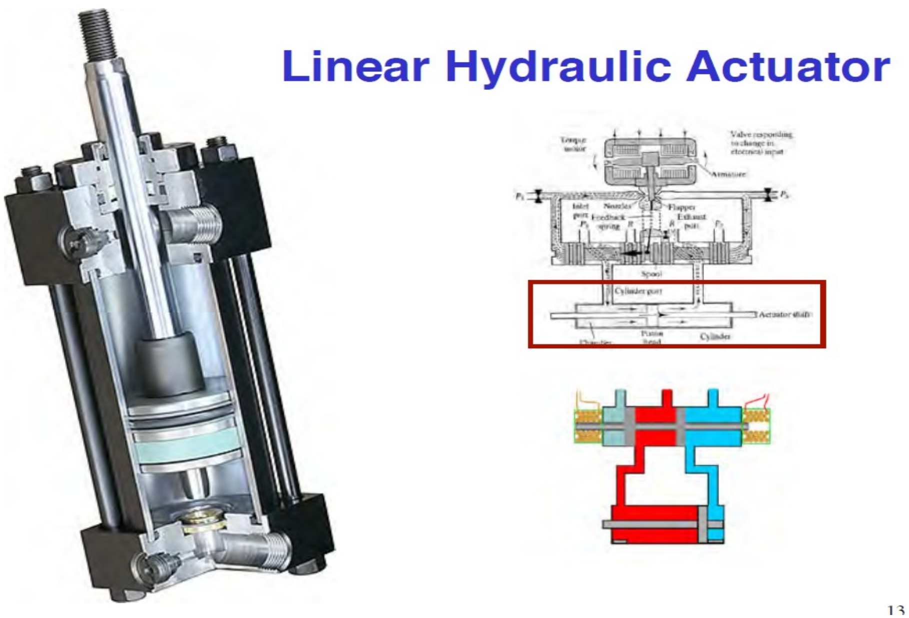
Applications: assembly tasks that requires precision, e.g. circuit board.

Adapted from: www.cs.ust.hk/~helens/comp322/lecture/Lecture-03.ppt

Classification of Robot Arms: by Drive Technology

- **Hydraulic System**
  - made up of an electric motor that pumps a non-compressible fluid into a system consisting of a reserve tank, control valves and actuators to transmit energy.
  - generally associated with larger robots
  - Advantages:
    - greater power, i.e. can handle heavy load
    - greater speed
  - Disadvantages:
    - occupies large floor space
    - tendency to leak oil => dirty
    - noisy

Applications: for heavy "dirty" task, e.g. welding in automobile and aircraft industries



Adapted from: www.cs.ust.hk/~helens/comp322/lecture/Lecture-03.ppt

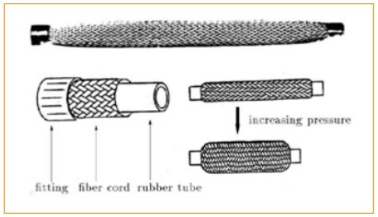
Classification of Robot Arms: by Drive Technology

- **Hydraulic System**
- **Electric System**
- **Pneumatic System**
  - Uses compressed air
  - for smaller robots with fewer degrees of freedom
  - Advantages:
    - Compliance - uyunç
  - Disadvantages:
    - difficult to provide good precision due to the fact that air is compressible , easily affected by temp., humidity, etc.
  - Applications:control of grippers to provide compliance in grasping objects

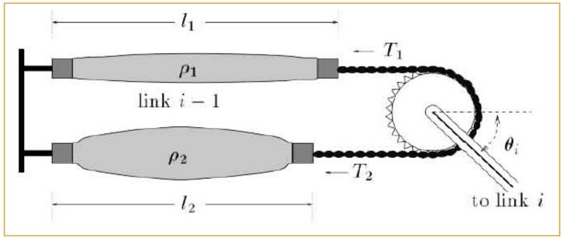
Rubbertuator

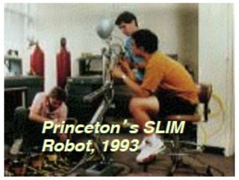
Pneumatic analog of muscle

Contraction under pressure

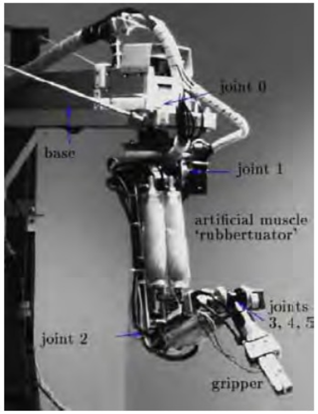


Agonist-antagonist action produces rotation





Robot arm



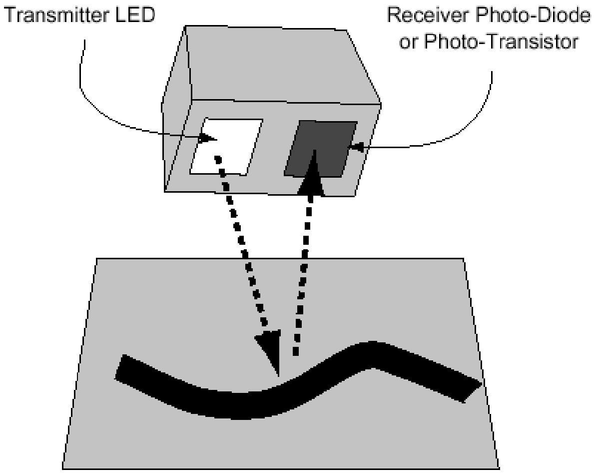
12

The term compliance refers to flexibility and suppleness. To define what compliance is, the definition of non-compliance is useful. A non-compliant (stiff)

Adapted from: www.cs.ust.hk/~helens/comp322/lecture/Lecture-03.ppt

Robot::Sensors

- Allow for perception.
- Sensors can be active or passive:
- *Active* – derive information from environment's reaction to robot's actions, e.g. bumpers and sonar.
- *Passive* – observers only, e.g. cameras and microphones .



https://www.slideshare.net/akhil_n12/introduction-to-robotics-15802680

SENSORS

Sensors provide awareness of the environment by sensing things. Sensors are the core of robots.

1- EXTEROCEPTORS (EXTERNAL SENSORS)

2- PRORIOCEPTORS(INTERNAL SENSORS)

Sensing can be in different forms like-

Light

Sound

Heat

Chemicals

Force

Object proximity

Physical orientation/position

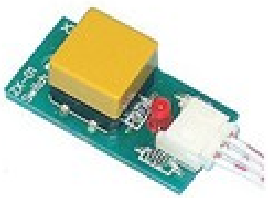
Magnetic & Electric Fields

Resistance

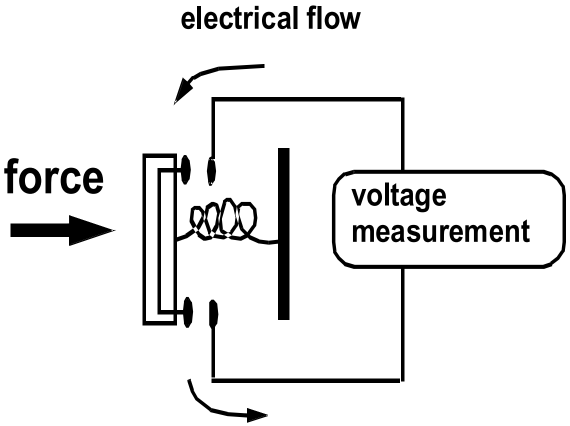
https://www.slideshare.net/VinitShahdeo/robotics-52226089

CLASSIFICATION OF EXTERIOCEPTORS

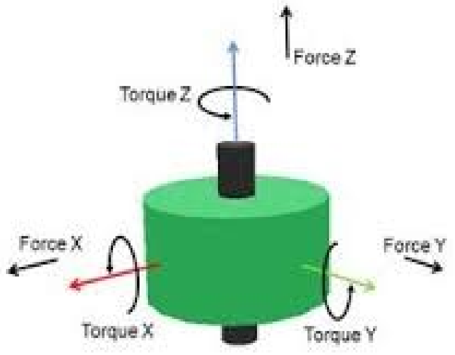
CONTACT SENSORS- Sensors that determine shape,size ,weight etc by touching.



Touch Sensor

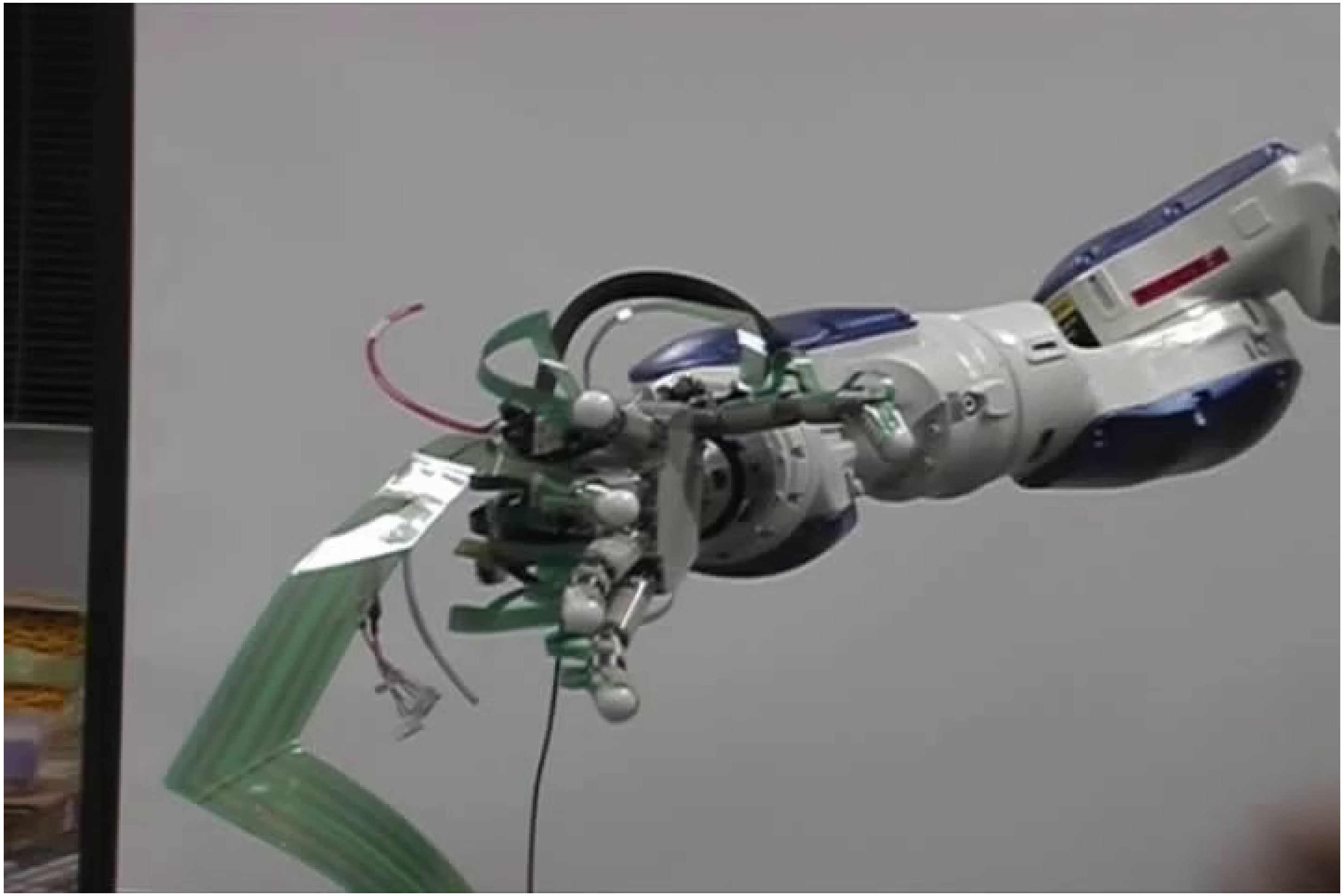


Force/stress sensors-To measure robotic system forces .



https://www.slideshare.net/.../robotic-sensors-12735819

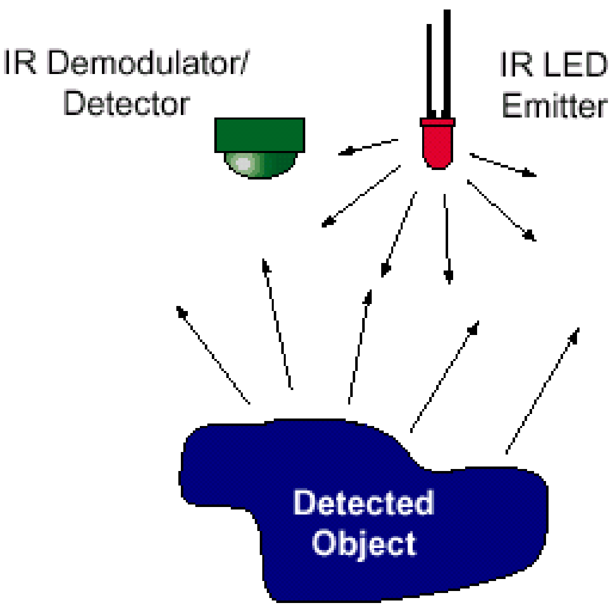
Compliance: Electric motor+force sensor

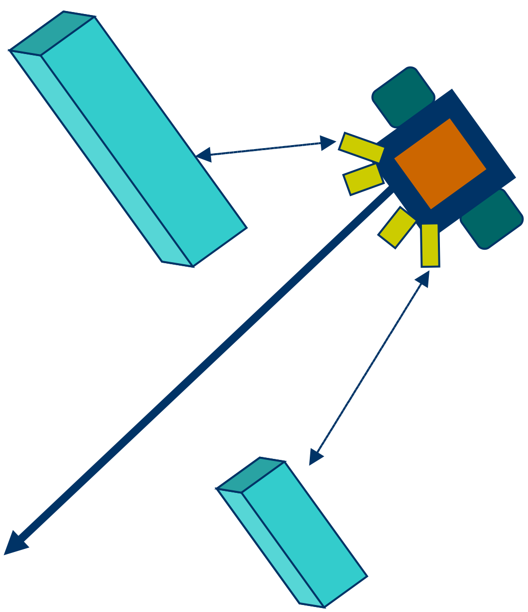


E. Ugur, H. Celikkanat, E. Sahin, Y. Nagai, and E. Oztop, Learning to Grasp with Parental Scaffolding, IEEE Intl. Conf. on Humanoid Robotics, pp. 480-486, Bled, Slovenia, 26-28 October, 2011.

Sensors: Vision and range sensors

- *Range sensors*: these sensors are used to determine distances from other objects, e.g. bumpers, sonar, lasers, whiskers, and GPS.
  - Active. send signal into environment and measure interaction of signal with environment, e.g. radar, sonar
- Passive: camera





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Sensors: Vision and range sensors