Advancing Sustainability of Process Industries through Digital and Circular Water Use Innovations

AquaSPICE Summer School

Robotics in Industry 4.0

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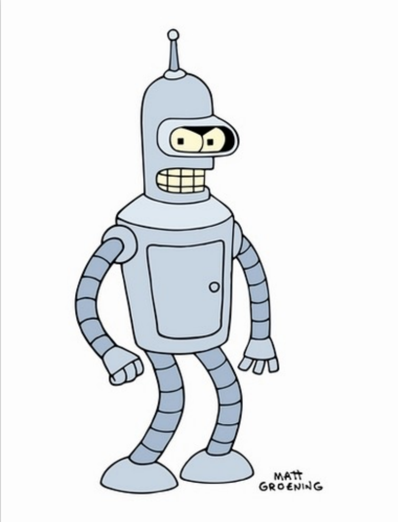
The AquaSPICE project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 958396.

Let us start from the basics…



What is a robot?

There is no straightforward answer…

Definition 1: An electromechanical device that is: Reprogrammable, multifunctional and can sense/interact with the environment

Definition 2: A robot is an autonomous machine capable of sensing its environment, carrying out computations to make decisions, and performing actions in the real world[1].

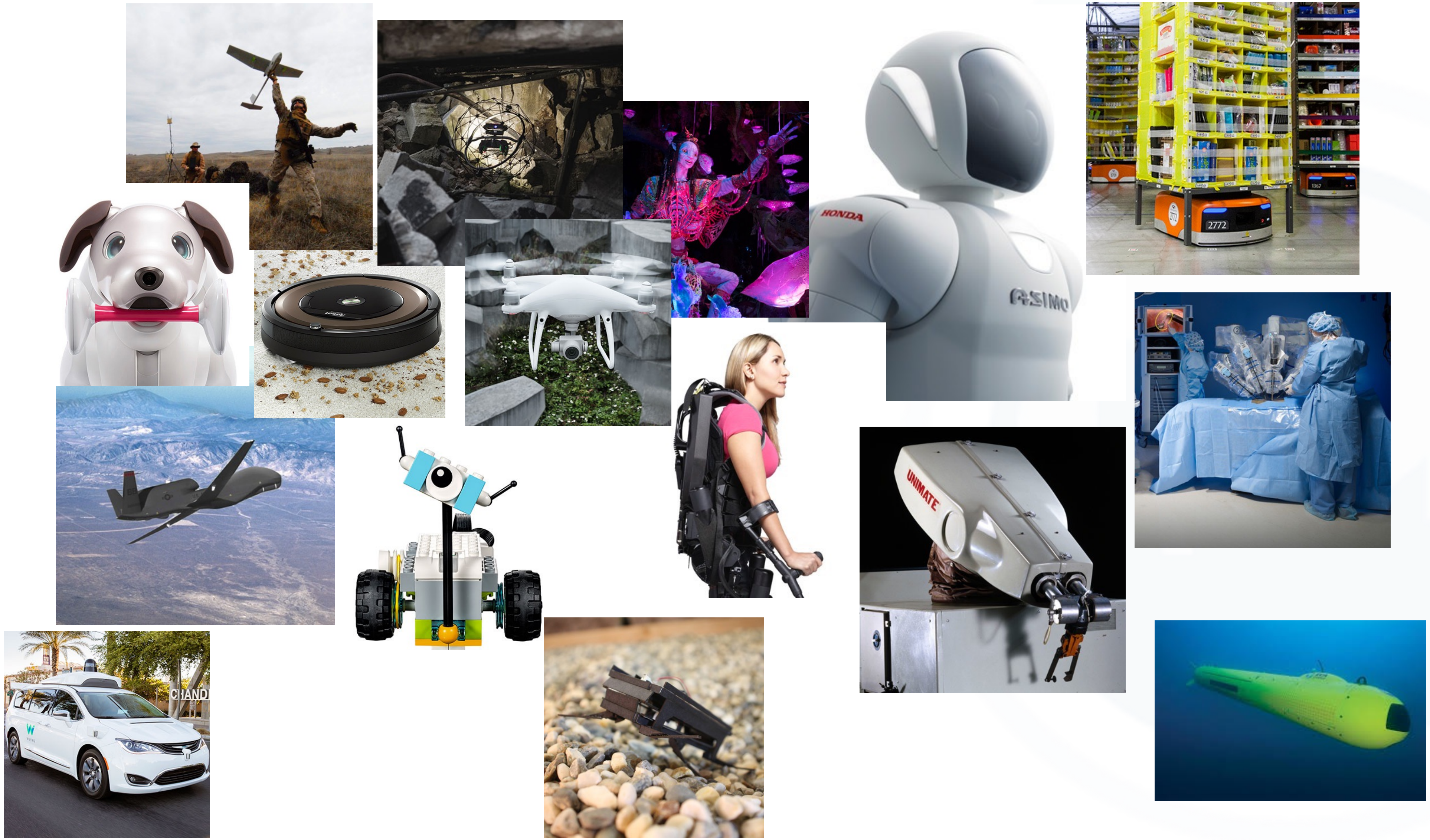
[1] https://robots.ieee.org/learn/

Why we use robots?

- Robots are ideal, among others, for working in 4D environments!
  - Dangerous
  - Dirty
  - Dull
  - Difficult
- They offer significant advantages including but not limited to:
  - Increased product quality
  - Increased efficiency
  - Increased safety
  - Reduced Cost
  - Reduced manufacturing lead time
  - Increased productivity

Classification based on the robot's functionality[1]

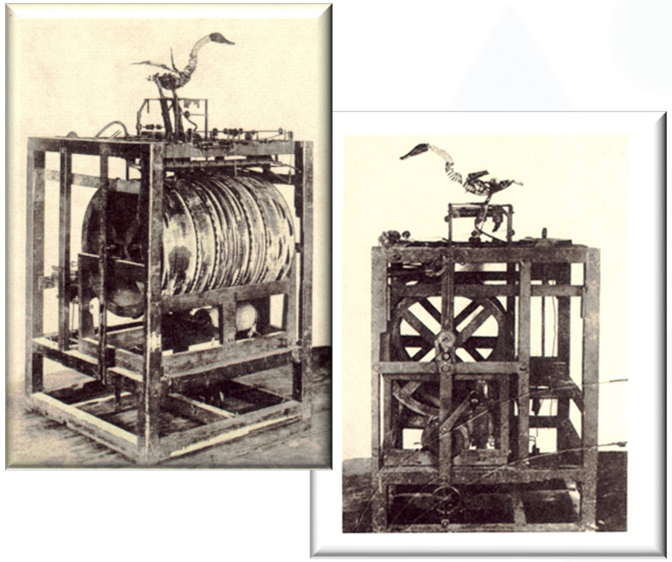
- Aerospace
- Consumer
- Disaster/response
- Drones
- Education
- Entertainment
- Exoskeletons
- Humanoids
- Industrial
- Medical
- Military & Security
- Research
- Self-Driving cars
- Telepresence
- Underwater



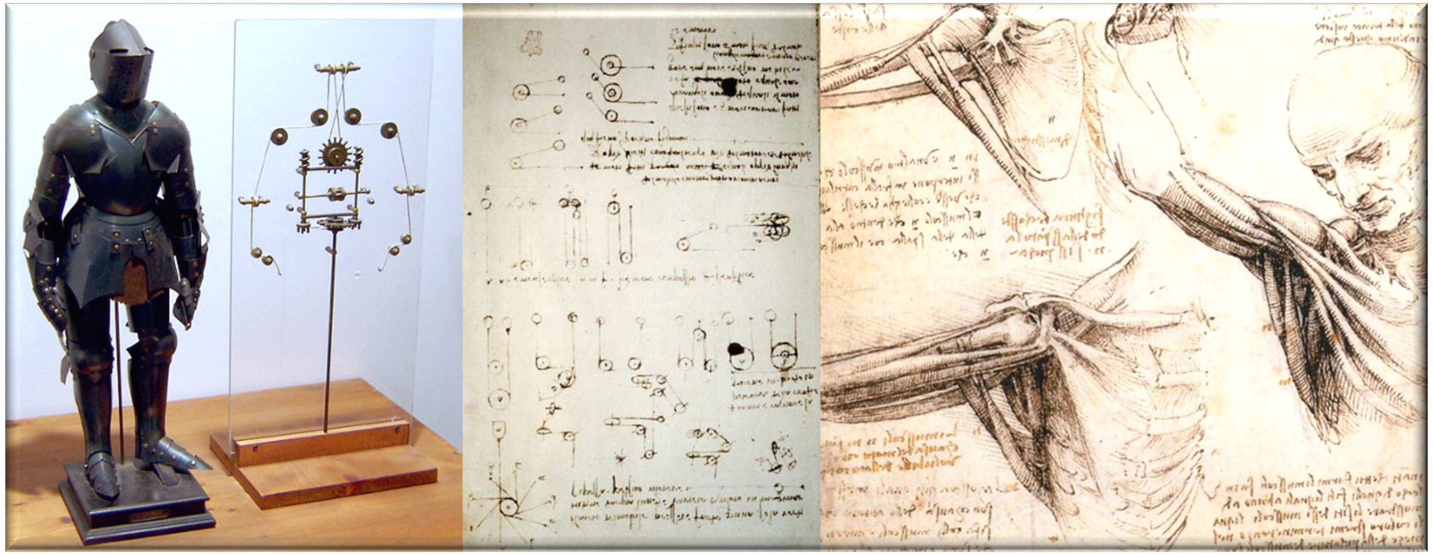
[1] https://robots.ieee.org/learn/types-of-robots/

Are robots a new concept? A brief history lesson…

Talos: Mythical guardian of the Island of Crete, constructed by the God Hephaestus



Automata: a machine or control mechanism designed to follow automatically a predetermined sequence of operations or respond to encoded instructions



Leonardo's robot, or Leonardo's mechanical knight (Italian: Robot di Leonardo or Automa cavaliere, lit. "Automaton knight") , was a humanoid automaton designed and possibly constructed by Leonardo da Vinci around the year 1495[1].

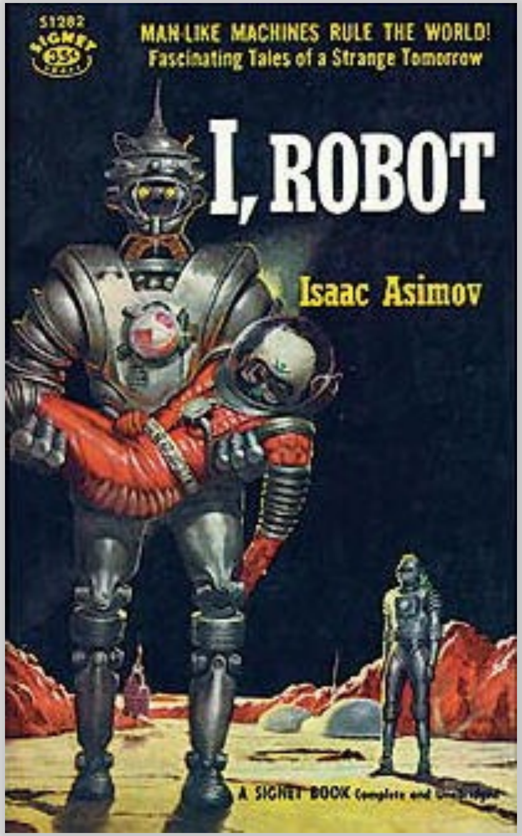
https://en.wikipedia.org/wiki/Leonardo%27s_robot

Are robots a new concept? A brief history lesson…

- **1922:** Karel Čapek introduced and made popular the frequently used international word robot, which first appeared in his play R.U.R. (Rossum's Universal Robots) in 1920[1]. This play referred to small humanoid creatures, which were doing hard labor and eventually revolted against their master. This literature work “shaped” the public belief about how the robots are supposed to look like and what is there role in the society. The word **robot** comes from the word **robota**, meaning literally "**serf labor**", and, figuratively, "drudgery" or "hard work" in modern Czech.
- **1926:** The german film Metropolis introduces the robot Electro[2].

[1]http://en.wikipedia.org/wiki/Karel_%C4%8Capek
[2]http://en.wikipedia.org/wiki/Metropolis_%28film%29

Are robots a new concept? A brief history lesson…



- **1947:** The first robotic manipulators were introduced due to the need to handle radio material. The first manipulators were known as teleoperators and allowed the human to handle materials with safety from a remote distance.
- **1950:** The famous book of **Isaac Asimov's** "I, Robot", is published. It contains nine short stories about robots and in one of them is introducing the three laws of robotics

- A robot may not injure a human being or, through inaction, allow a human being to come to harm.
- A robot must obey the orders given to it by human beings, except where such orders would conflict with the First Law.
- A robot must protect its own existence as long as such protection does not conflict with the First or Second Law.

Are robots a new concept? A brief history lesson…

- **1956:** George Devol applied for a patent for the first programmable robot, later named 'Unimate'. The patent was awarded on **1961.**
- **1961:** The first Unimate robot is installed in a Trenton, NJ General Motors plant to tend a die casting machine. The key was the reprogrammability and retooling of the machine to perform different tasks.
- **1962:** Unimation, Inc. was formed, (Unimation stood for "Universal Automation")
- **1966-1968:** "Shakey[1]," the first intelligent mobile robot system was built at Stanford Research Institute, California.
  - First **mobile robot**, which used AI techniques. It was able to recognize objects using vision, navigate autonomously and interact with objects (*almost 50 years ago!!!!*).

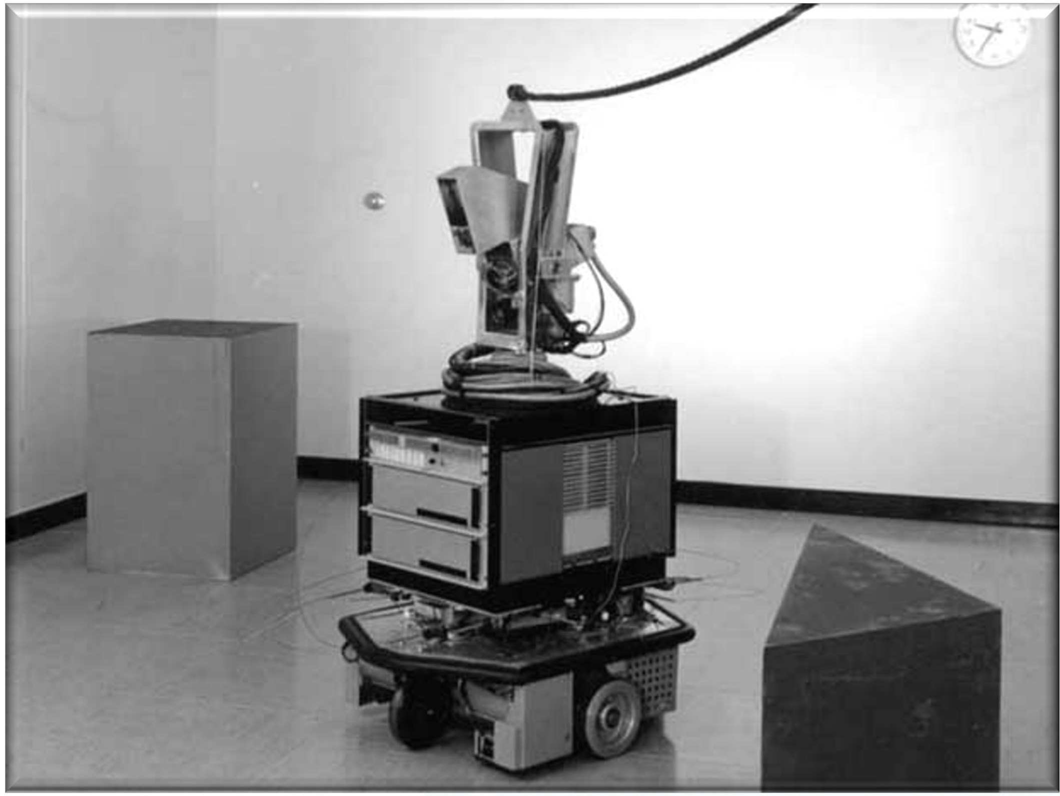


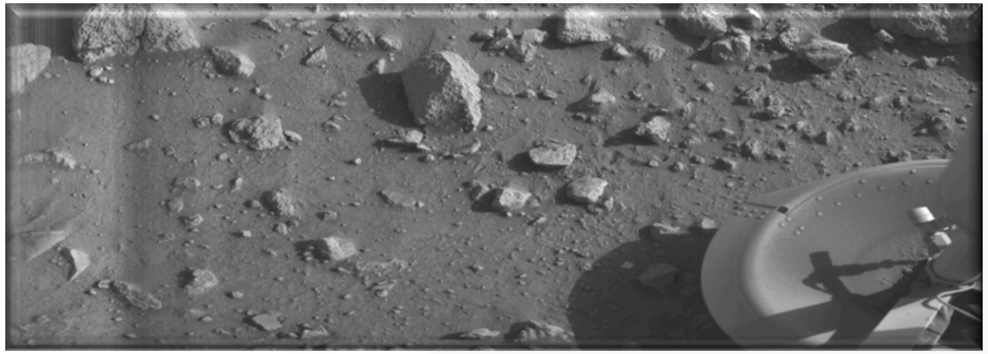
Photo: SRI International

[1] http://theinstitute.ieee.org/tech-history/technology-history/straight-out-of-scifi-shakey-was-the-first-mobile-robot-built-with-ai

Are robots a new concept? A brief history lesson…

- **1967:** The first industrial robot able to perform painting processes is used in Japan.
- **1970 -** Luna 17 lands on the moon, carrying the roving remote-controlled robot, Lunokhod 1.
- **1971:** Japan’s Robot Association is founded under the name Industrial Robot Conversazione.
- **1971 -1973:** The Stanford Arm is developed, along with the first language for programming robots - WAVE.
- **1972**: First snake-like robot – ACM III – Hirose – Tokyo Inst. Of Tech.
- **1970’s: JPL** develops its first planetary exploration Rover using a TV camera, laser range finder and tactile sensors.
- **1975:** The space probes **Viking** 1 and 2 were launched each with an articulated robot arm.
- **1976:** The film **Star Wars** is released introducing **R2-D2** and **C-3PO.**

Photo: https://en.wikipedia.org/wiki/Viking_1



First "clear" image ever transmitted from the surface of Mars shows rocks near the *Viking 1* Lander (July 20, 1976)

Are robots a new concept? A brief history lesson…

- **1978: General Motors** signs a contract with **Unimate** to build a **PUMA** (**P**rogrammable **U**niversal **M**achine for **A**ssembly) robot. Capable of production speed never before achieved, the robots built 110 cars per hour - more than double the rate of any automotive plant in existence at the time.
- **1979**: **SCARA** (**S**elective **C**ompliant **A**rticulated **R**obot for **A**ssembly) introduced in Japan and the US (by Adept Technologies).
- **1981: IBM** enters the robotics field with its 7535 and 7565 Manufacturing Systems.

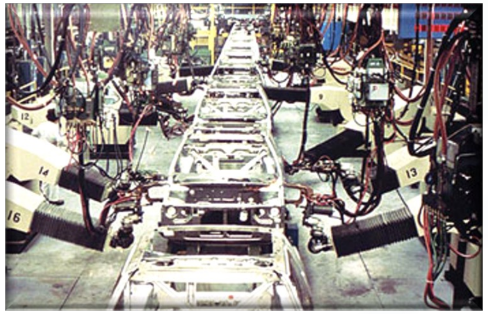
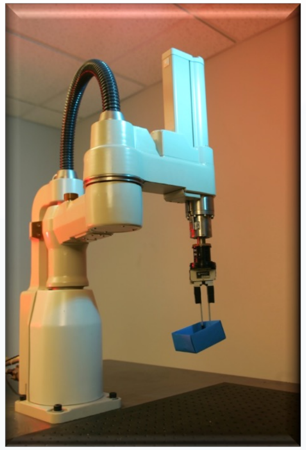


Photo: https://www.robotics.org/joseph-engelberger/unimate.cfm

Photo: https://www.ibm.com/ibm/history/exhibits/robotics/robotics_3.html

PUMA Robot

Source: TEMPUS IV Project: 158644 – JPCR Development of Regional Interdisciplinary Mechatronic Studies - DRIMS

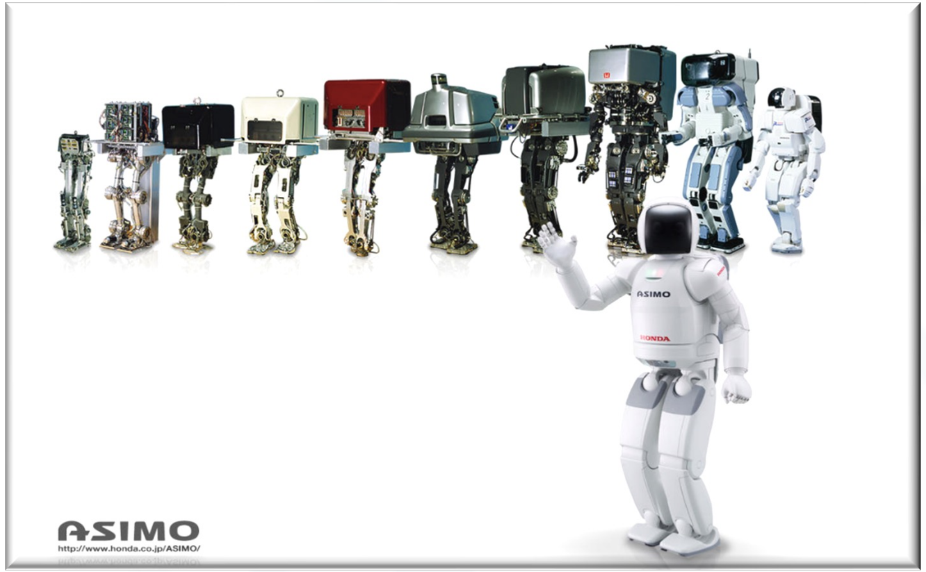


SCARA Robot

Source: TEMPUS IV Project: 158644 – JPCR Development of Regional Interdisciplinary Mechatronic Studies - DRIMS

Are robots a new concept? A brief history lesson…

- **1986: Honda** starts work on its first humanoid, robot named 'E0' (later to become **ASIMO**).
- **1991:** First **HelpMate** mobile autonomous robot used in hospitals.
- **1990's:** The era of Humanoid robots starts. Cog, Kismet (MIT), Wasubot, WHL-I – Japan, Honda P2 (1.82m, 210kg), and P3 (1.6m, 130kg), ASIMO are some of the best samples.
- **1990's**: Entertainment and Education Robots like Sony AIBO, LEGO Mindstorms, Khepera, Parallax are introduced in the market.
- **1994:** Dante II was the first robot that entered a volcano (Mt.Spurr, Alaska) and collected samples
- **1997:** The first official **RoboCup** games and conference was held in 1997 with great success. Over 40 teams participated (real and simulation combined), and over 5,000 spectators attended.



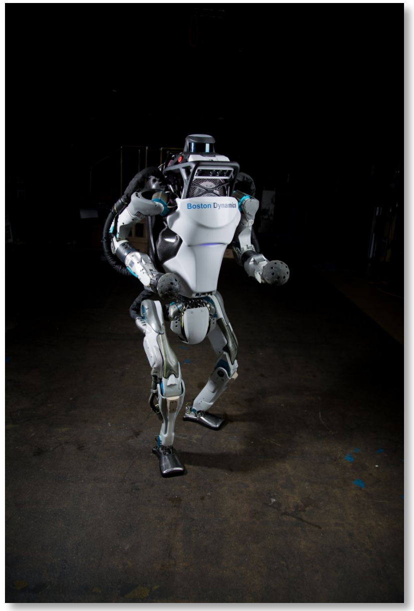
Are robots a new concept? A brief history lesson…

- **1997: Sojouner** (Mars pathfinder robot), operated autonomously for 83 days on Mars and transmitted valuable information.
- **2001: Canadarm2** is placed on the international space station.
- **2001: Global Hawk** was the 1st UAV that flew autonomously over the Pacific Ocean.
- **2001: CRASAR** uses small robots in the rumbles of the World Trade Center.
- **2002:** iRobot introduces **Roomba**, a personal robotic vacuum cleaner.
- **2005: Stanley** wins the DARPA Grand Challenge by autonomously navigating over an unknown terrain (for over 150 miles) in the desert.
- **2010: NASA** and **General Motors** join forces to develop Robonaut-2, the new version of NASA's humanoid robot astronaut.

Photo: iRobot

Photo: NASA

The last ten years…



Atlas © 2018 Boston Dynamics

Photo: Deepfield Robotics

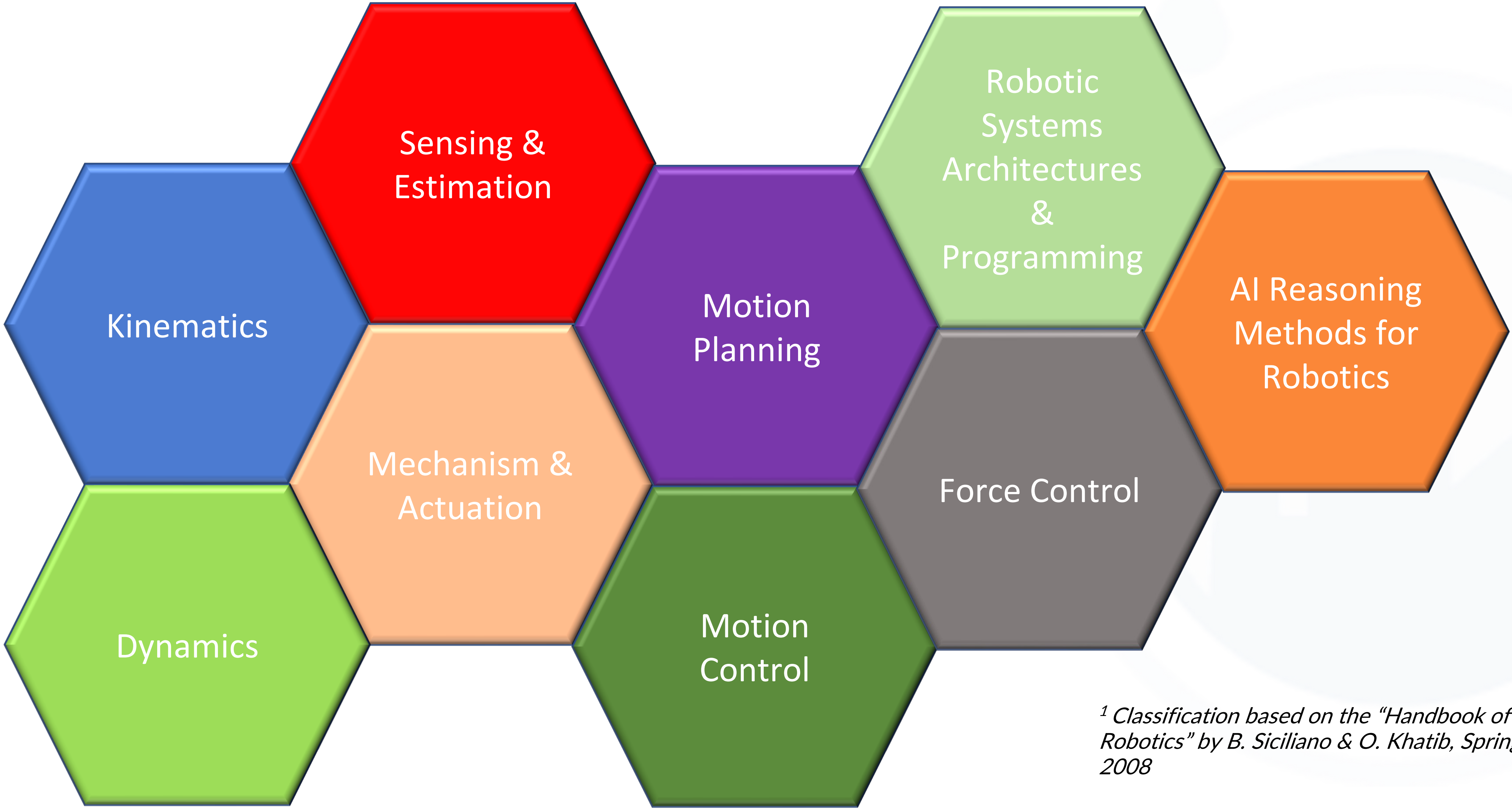
AscTec Firefly ©2018 Intel Deutschland GmbH

iCub (http://www.icub.org/)

Photo: Ford's autonomous vehicle

Roomba: iRobot

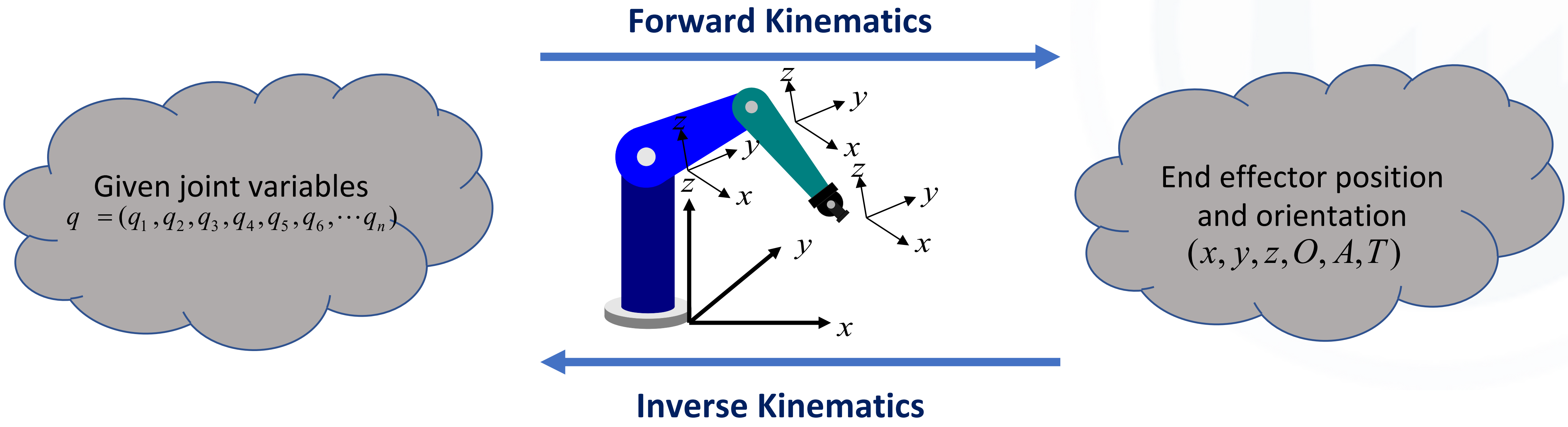
Fundamental principles & methods for modelling, designing, and controlling a robotic system[1]



[1] Classification based on the "Handbook of Robotics" by B. Siciliano & O. Khatib, Springer, 2008

Kinematics

- Kinematics pertains to the motion of bodies in a robotic mechanism **without regard to the forces/torques that cause the motion**.
- Kinematics is the most fundamental aspect of robot design, analysis, control, and simulation.
- Why kinematics?
  - Compute the workspace, the forward and inverse kinematics, the forward and inverse instantaneous kinematics, and the static wrench transmission of a robotic mechanism.



Dynamics

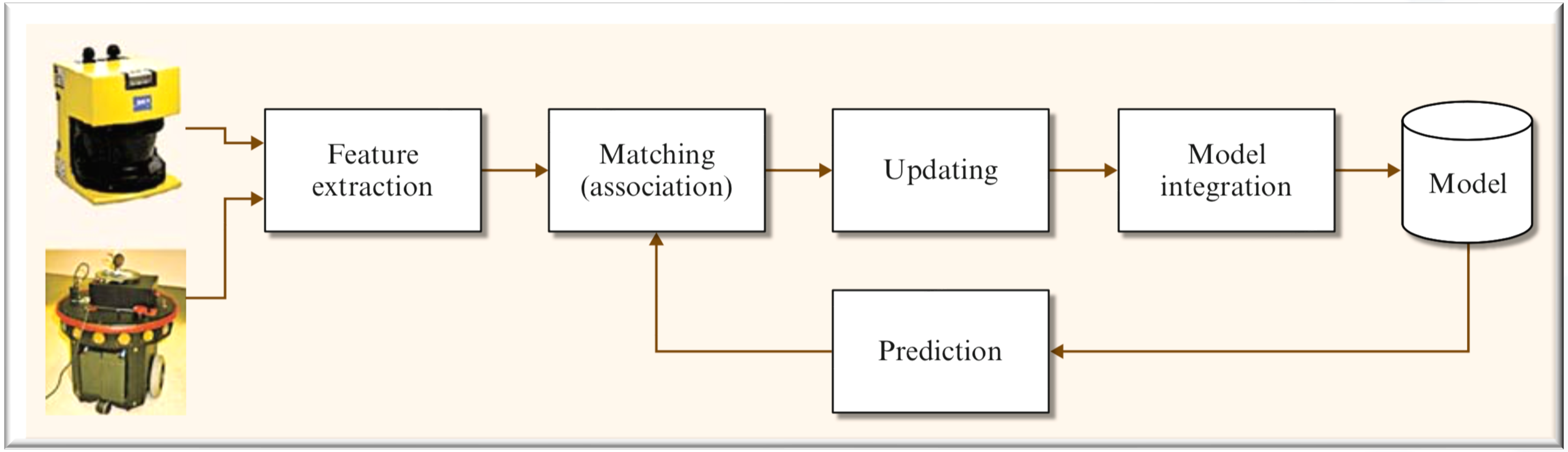
- The dynamic equations of motion provide the relationships between actuation and contact forces acting on robot mechanisms, and the acceleration and motion trajectories that result.
- Dynamics is important for mechanical design, control, and simulation.
- A number of algorithms are important in these applications, and include computation of the following: inverse dynamics, forward dynamics, the joint-space inertia matrix, and the operational-space inertia matrix.
  - Inverse dynamics, in which the required joint actuator torques/forces are computed from a specification of the robot's trajectory (position, velocity, and acceleration).
  - Forward dynamics in which the applied joint actuator torques/forces are specified and the joint accelerations are to be determined.
  - The joint-space inertia matrix, which maps the joint accelerations to the joint torques/forces.
  - The operational-space inertia matrix, which maps task accelerations to task forces in operational or Cartesian space.

Mechanism and Actuation

- The **kinematics equations and Jacobian** of the robot characterize its **range of motion** and **mechanical advantage**, and guide the selection of its **size** and **joint arrangement**. Dynamics is important for mechanical design, control, and simulation.
- The **tasks** a robot is to perform, and the associated precision of its movement determine detailed features such as **mechanical structure, transmission, and actuator selection**.
- The primary features that characterize a robot are its **work envelope** and **load capacity**.
  - The space in which a robot can operate is its work envelope, which encloses its workspace.
  - Load capacity, a primary robot specification, is closely coupled with acceleration and speed.
- Manipulator **shape** and **size** is determined by requirements on its workspace shape and layout, the precision of its movement, its acceleration and speed, and its construction.

Sensing and Estimation

- Sensing and estimation are essential aspects of the design of any robotic system. At a very basic level, the state of the robot itself must be estimated for feedback control. At a higher level, perception, which is a task-oriented interpretation of sensor data, allows the integration of sensor information across space and time to facilitate planning.

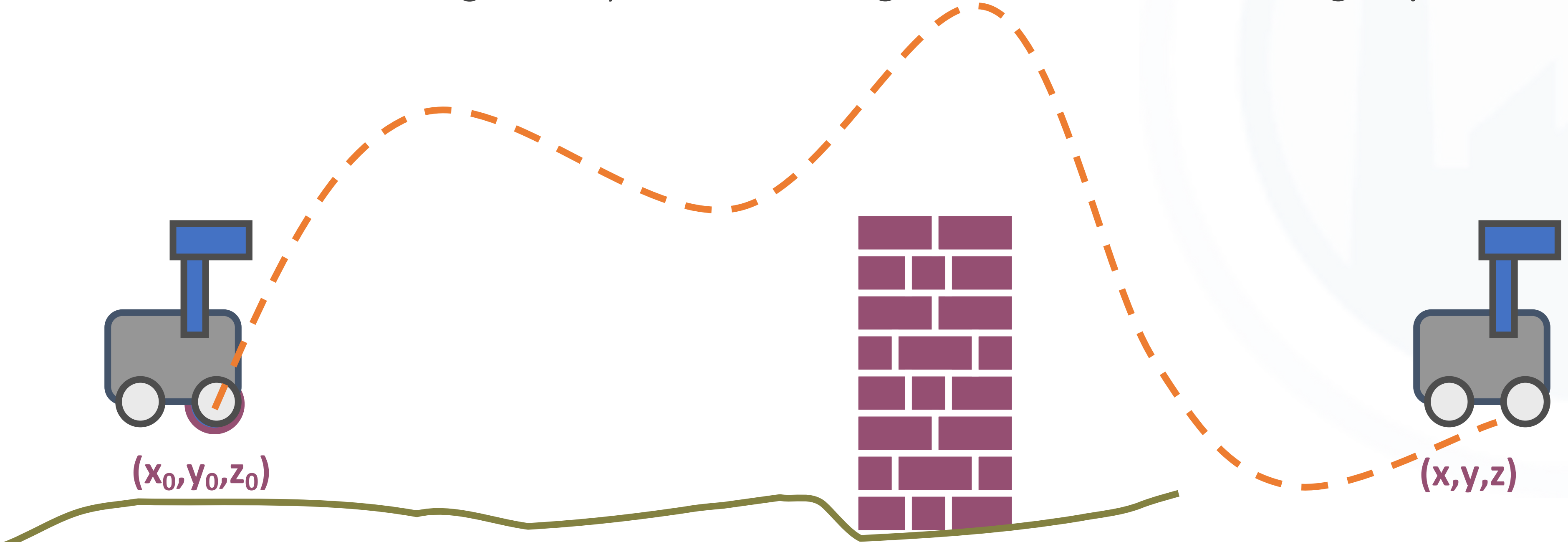


Handbook of Robotics" by B. Siciliano & O. Khatib, Springer, 2008

Classification	Sensor type
Tactile sensors	Switches/bumpers Optical barriers Proximity
Haptic sensors	Contact arrays Force/torque Resistive
Motor/axis sensors	Brush encoders Potentiometers Resolvers Optical encoders Magnetic encoders Inductive encoders Capacity encoders
Heading sensors	Compass Gyroscopes Inclinometers
Beacon based (postion wrt an inertial frame)	GPS Active optical RF beacons Ultrasound beacon Reflective beacons
Ranging	Capacitive sensor Magnetic sensors Camera Sonar Laser range Structures light
Speed/motion	Doppler radar Doppler sound Camera Accelerometer
Identification	Camera Radio frequency identification RFID Laser ranging Radar Ultrasound Sound

Motion Planning

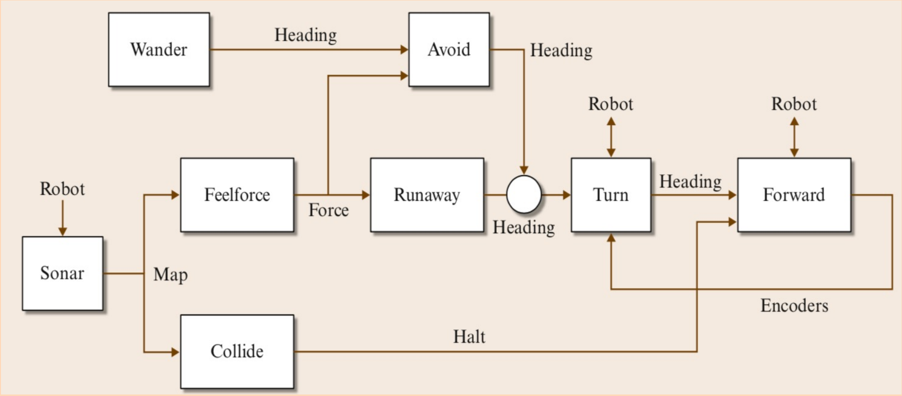
- The problem of motion planning can be stated as follows. Given:
  - A **start pose** of the robot
  - A desired **goal pose**
  - A geometric description of the robot
  - A geometric description of the world
- Find a **path** that **moves the robot** gradually from **start** to **goal** while **never touching any obstacle**



- Robot software systems are **complex!**
  - This complexity is due, in large part, to the need to control **diverse sensors** and **actuators** in **real time**, in the face of significant **uncertainty and noise**. Robot systems must work to achieve tasks while **monitoring for, and reacting to, unexpected situations**.
- A good architecture combined with the appropriate programming tools to support it, may manage the complexity.
- Currently there is no single architecture which is applicable in all cases and all devices.
- Although robot architectures heavily involve software engineering/architecture they distinguish from it, because robot systems need to interact **asynchronously, in real time, with an uncertain, often dynamic, environment.**

Early Approaches….

The sense–plan–act (SPA) paradigm



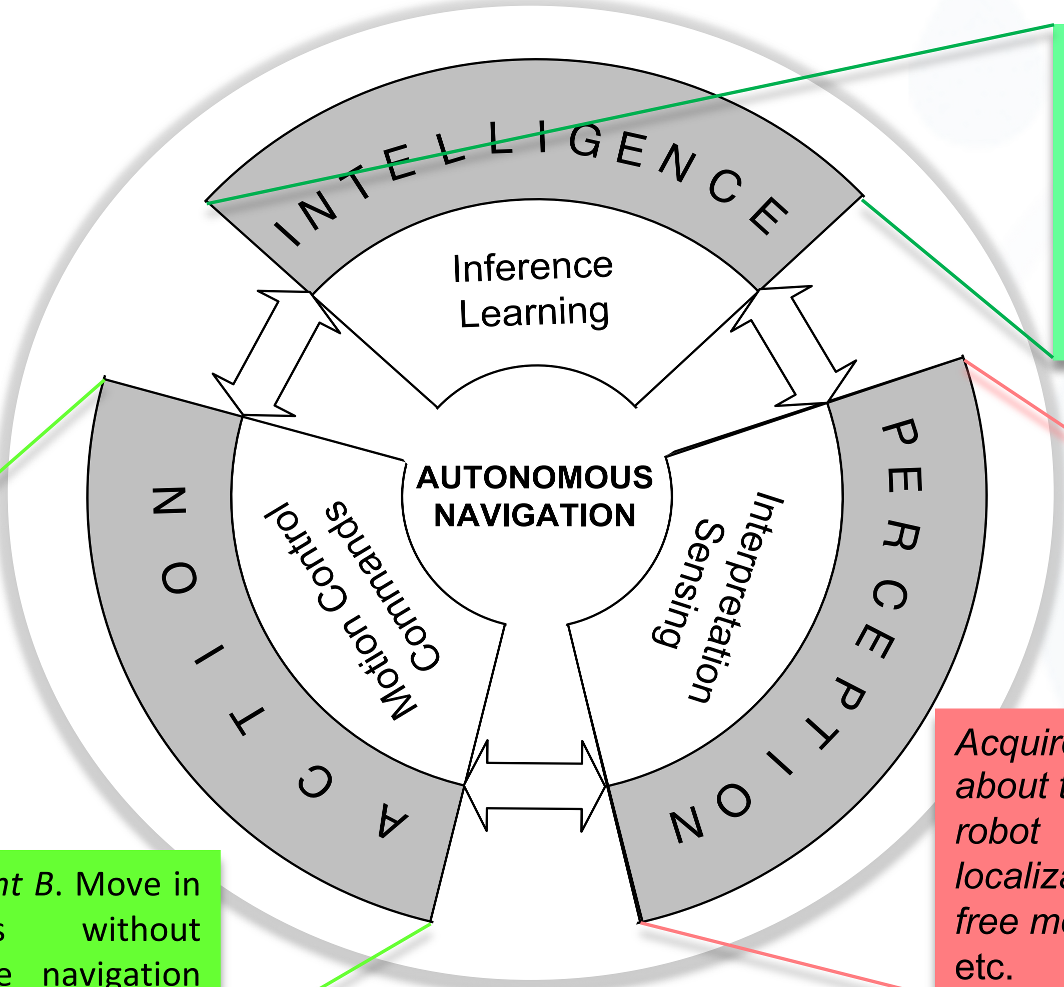
Example of the Subsumption architecture

"Handbook of Robotics" by B. Siciliano & O. Khatib, Springer, 200

AI Reasoning Methods for Robotics

- Artificial Intelligence reasoning is successful in different kind of application but still it is not directly applicable to robotics.
- Why?
- Knowledge representation and inference i.e. Logic based representation, probability-based approaches.
    - Logic based high-level control.
    - Fuzzy Logic.
- Action Planning.
- Machine Learning
    - Inductive Logic Learning
    - Statistical Learning and Neural Networks
    - Reinforcement Learning

But what we truly need to have autonomous robots?



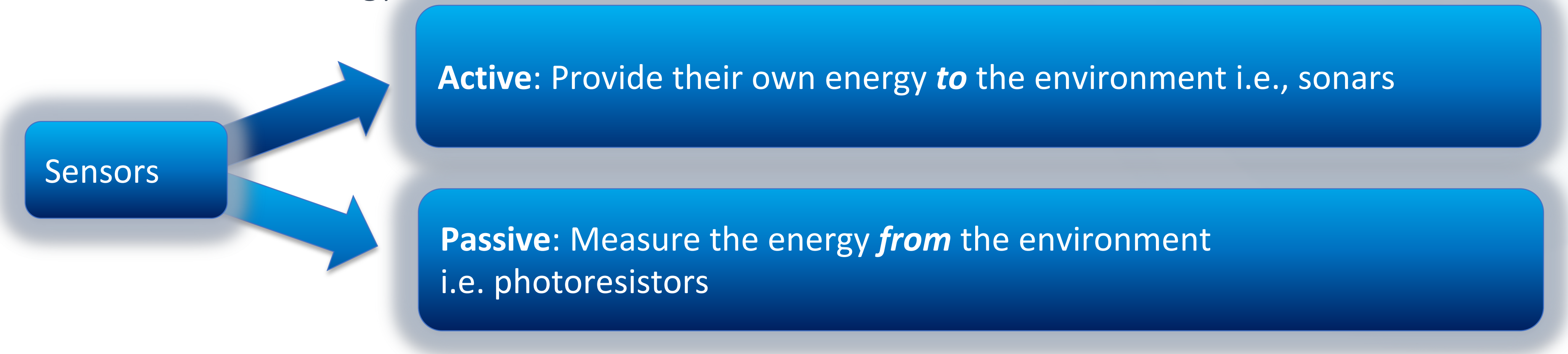
Operate for a considerable time period without human intervention. Learning and inference capabilities are needed for adaptation.

Travel from point A to point B. Move in dynamic environments without involving humans in the navigation loop.

Acquire and use knowledge about the environment and the robot itself. Here belongs *localization*, *planning*, *collision free motion control, recharging,* etc.

Understand / Perceive the environment where the robot is operating. How?

- Using a sensor
  - A sensor is a converter that measures a physical quantity and converts it into a signal which can be read by an observer or by an electronic instrument.
- Using a transducer
  - A transducer is a device that converts a signal in one form of energy to another form of energy. Energy types include (but are not limited to) electrical, mechanical, electromagnetic (including light), chemical, acoustic and thermal energy.



What are the criteria for a sensor's selection?

- Field of view
- Accuracy
- Repeatability
- Resolution
- Compatibility with the environment
- Energy Consumption
- Reliability of the hardware
- Size
- Cost

Sensors division based on usability

- Position sensors
  - Localization
- Proximity sensors
  - Collision Avoidance
- Internal state sensors
  - What is the state of the various robot's components?
- Mission specific sensors
  - How the robot act in a specific task / mission?

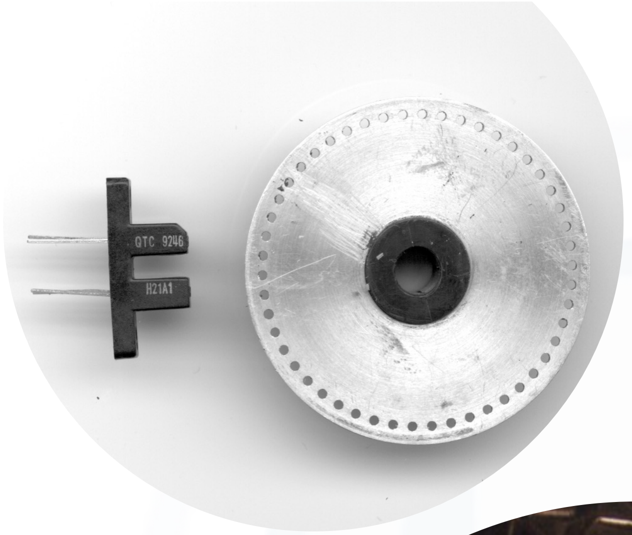
Position Sensors

- Provide information regarding the position, orientation and movement of a mobile robot
  - Position x,y,z
  - Orientation around x,y,z axis
  - Velocity, accelaration
- Sample sensors
  - Different type of encoders (optical, magnetic etc.)
  - Gyroscopes, accelerometers
  - Compasses
  - Inertial Navigation Systems (INS)
  - Global Position Systems (GPS)

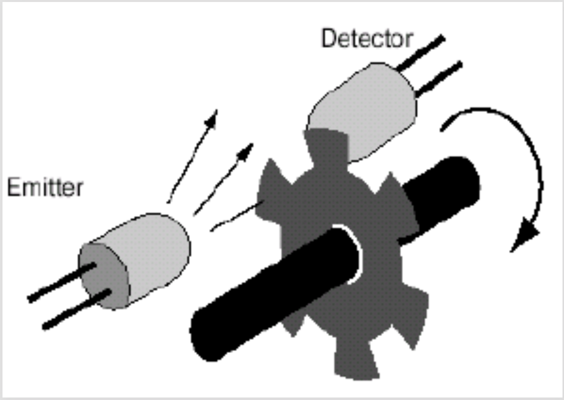
Position Sensors - Encoders

- Encoders (optical, magnetic etc.) are used to calculate the position of a moving robot (relative to a known starting location) based on **odometry**.

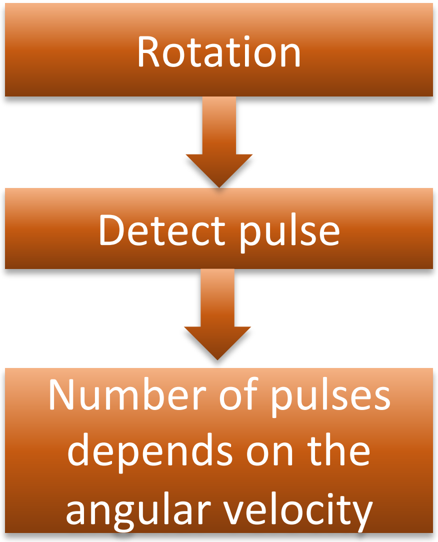
- Suppose a robot has rotary encoders on its wheels. It drives forward for some time and then would like to know how far it has traveled. It can measure how far the wheels have rotated, and if it knows the circumference of its wheels, compute the distance.

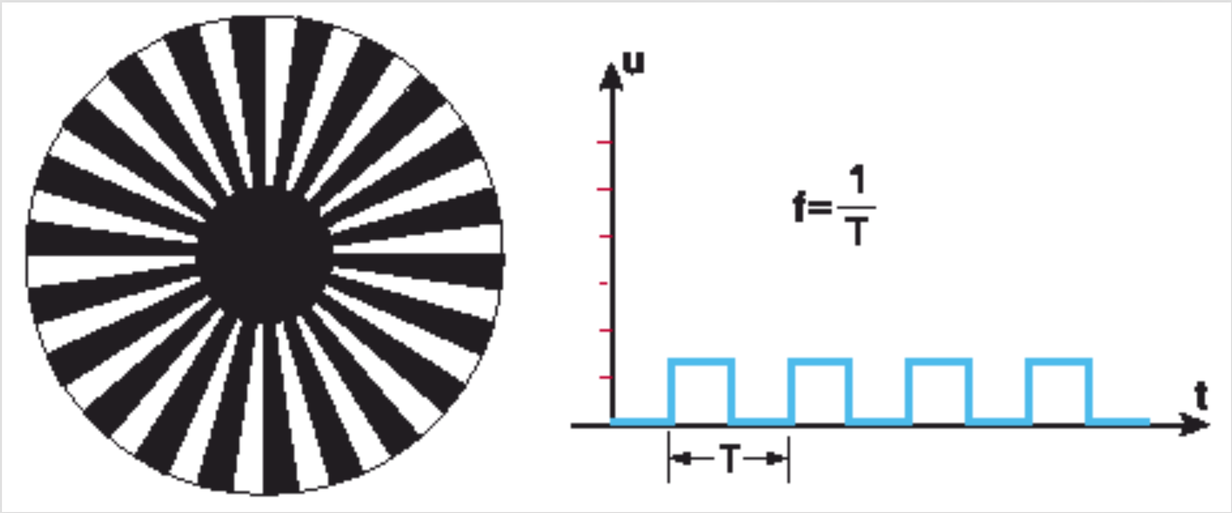


Position Sensors – Optical Encoders



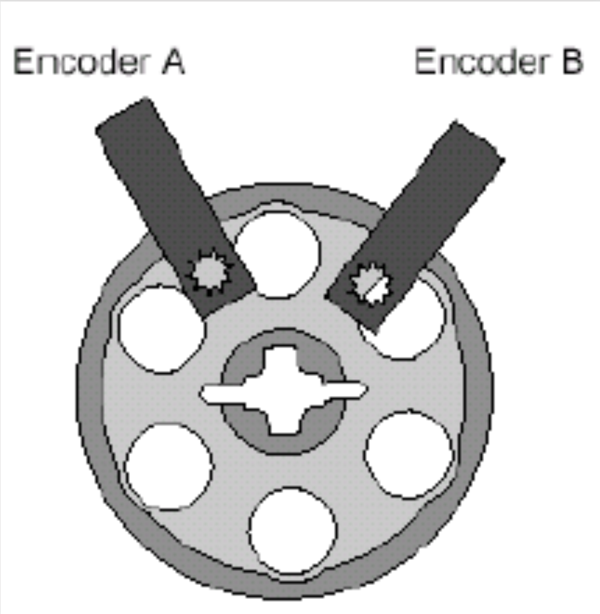
- An incremental encoder consists of:
  - A rotating part divided into transparent and non-transparent areas,
  - a light emitter,
  - a light detector

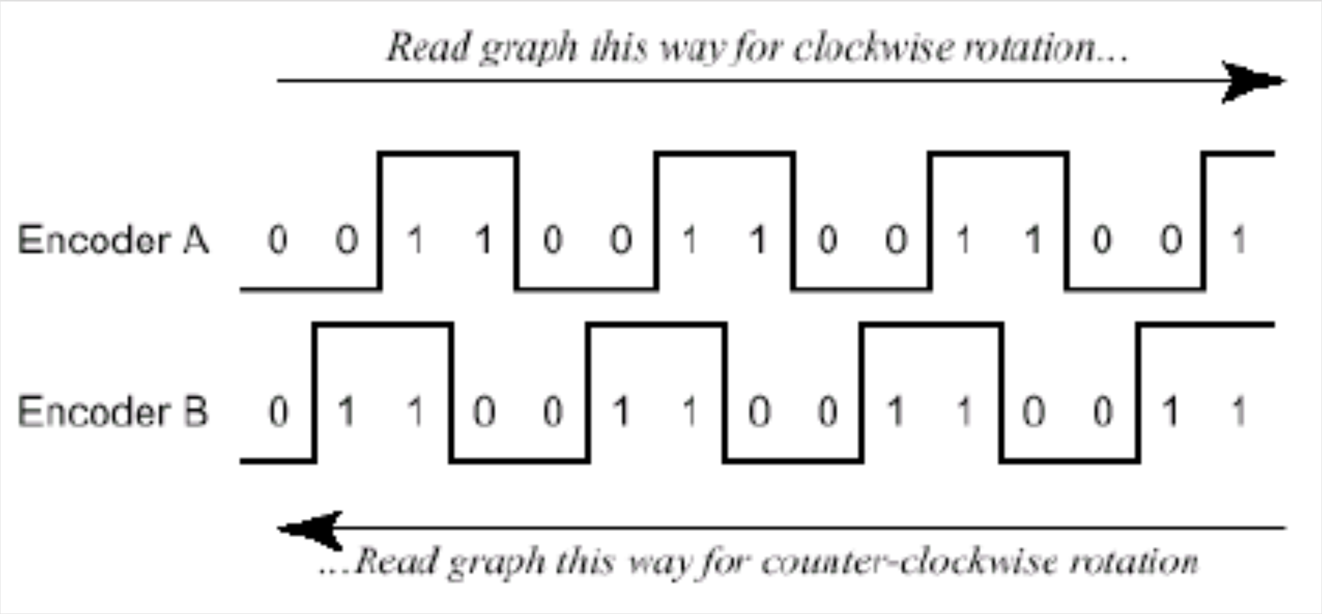




Position Sensors – Optical Encoders

- To identify if the mobile robot is moving forward or backwards, we can use two set of sensors so that the outputs are 90 degrees out of phase

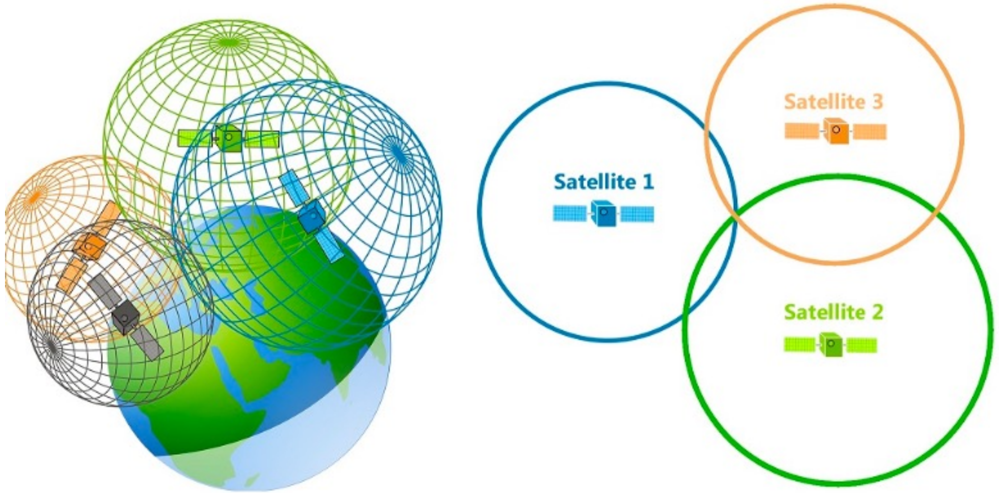




How can we obtain more accurate results concerning a robot's position especially outdoors?

- **By using the Global Positioning System (GPS)**; a space-based satellite navigation system that provides location and time information in all weather conditions, anywhere on or near the Earth where there is an unobstructed line of sight to four or more GPS satellites.

- GPS is widely used in mobile robotics, usually by fusing the information from the GPS sensor with information acquired by other means/sensors i.e., odometry, IMU's etc.



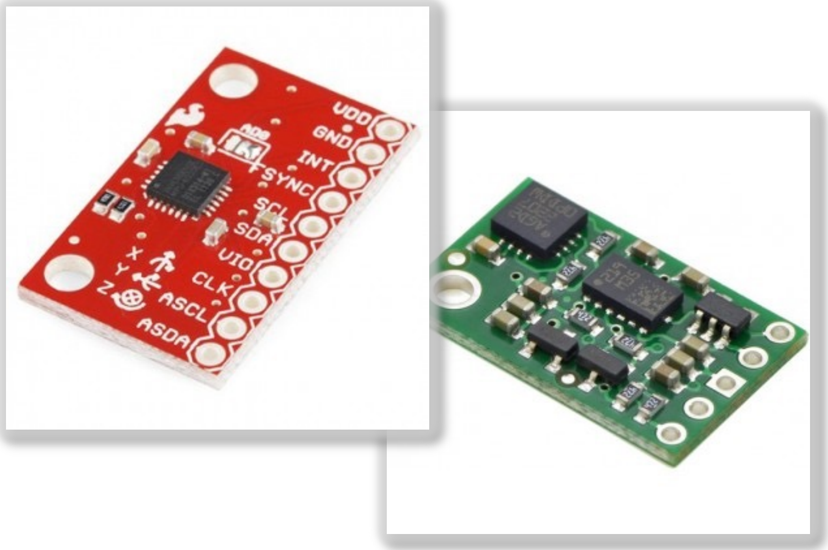
Gyroscopes

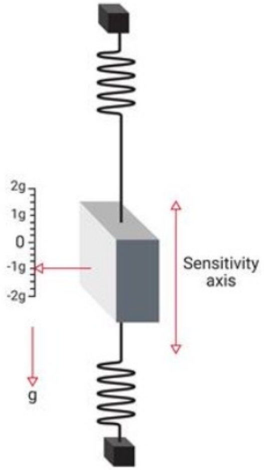
- Gyroscopes are devices for measuring or maintaining orientation.
- We use them to measure the relative orientation of a mobile robot.
- We can combine the information for more than one gyroscope, so that we can measure the rotation around more than one axis.
- It is important that the mounting point of a gyroscope in a device to be stable (i.e. without vibrations.
- There are three basic types of gyroscopes:
  - Spinning mass gyroscopes
  - Optical gyroscopes
  - Vibrating gyroscopes

Inertial Measurement Unit (IMU)

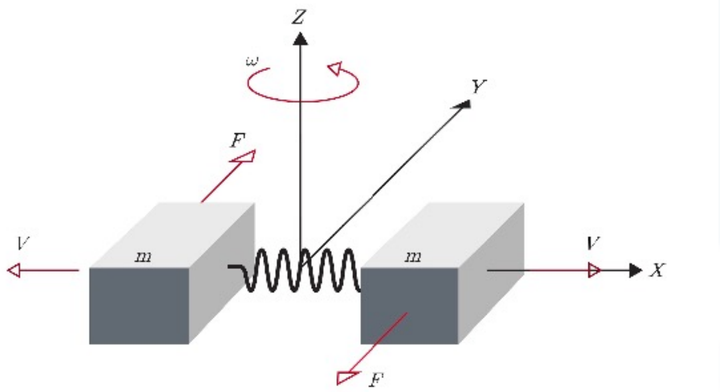
- An inertial measurement unit, or IMU, is an electronic device that measures and reports on a craft's velocity, orientation, and gravitational forces, using a combination of accelerometers and gyroscopes, sometimes also magnetometers[1].

- IMU devices became popular in robotics as their cost decreased significantly and because they can assist a robot to navigate efficiently especially in cases where there is no GPS signal





(a) IMU basic accelerometer model



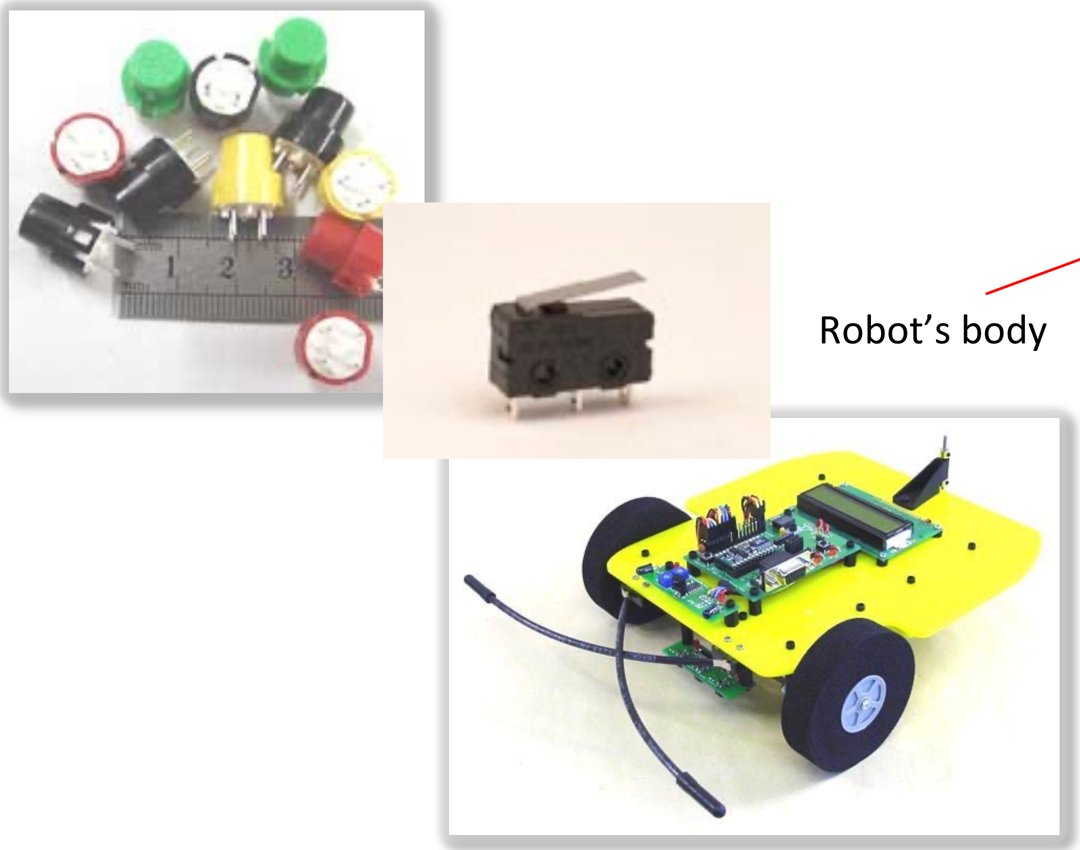
(b) IMU basic gyroscope model

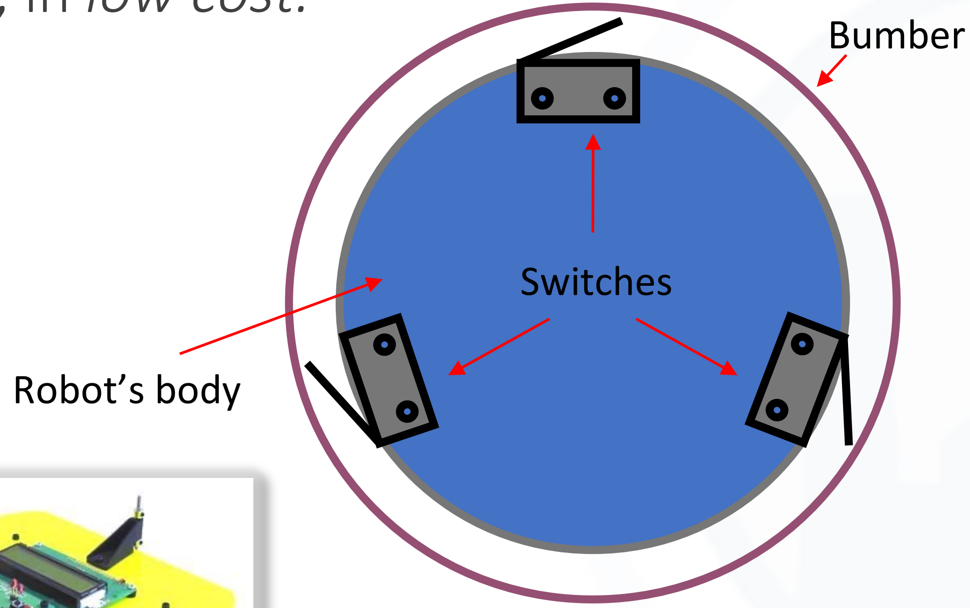
How can we detect an obstacle which is near a mobile robot?

- The **proximity sensors** provide information concerning the relative distance of the sensor from an object in the environment.
- The simplest form of sensors provides a boolean exit concerning the existence or not of an obstacle.
- More complicated sensors provide information even for the distance from an obstacle (the accuracy is depending on the device).
- They are mainly active sensors
- The most common types are:
  - Contact sensors
  - Infrared sensors
  - Ultrasonic sensors
  - Laser sensors
  - Vision based sensors
  - ….

Contact Sensors

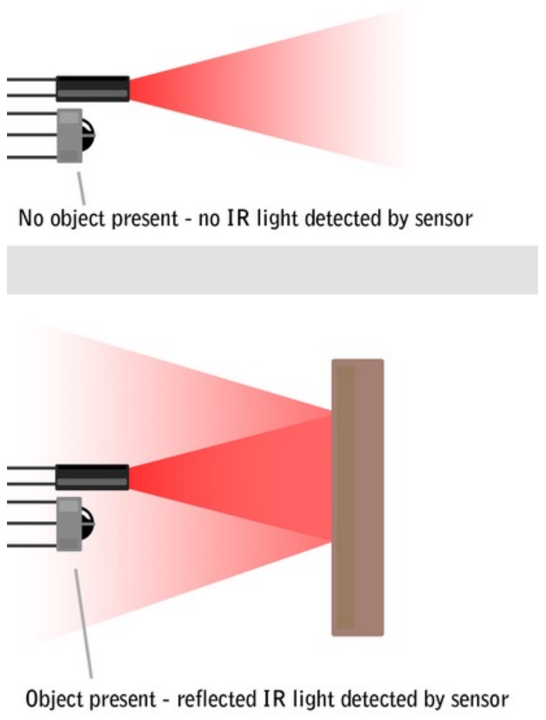
- The robot identifies an obstacle whenever the sensor has contact with it.
- These sensors are mainly switches, that change their state whenever there is contact.
- Different type of switches are available, in *low cost.*





Infrared Sensors

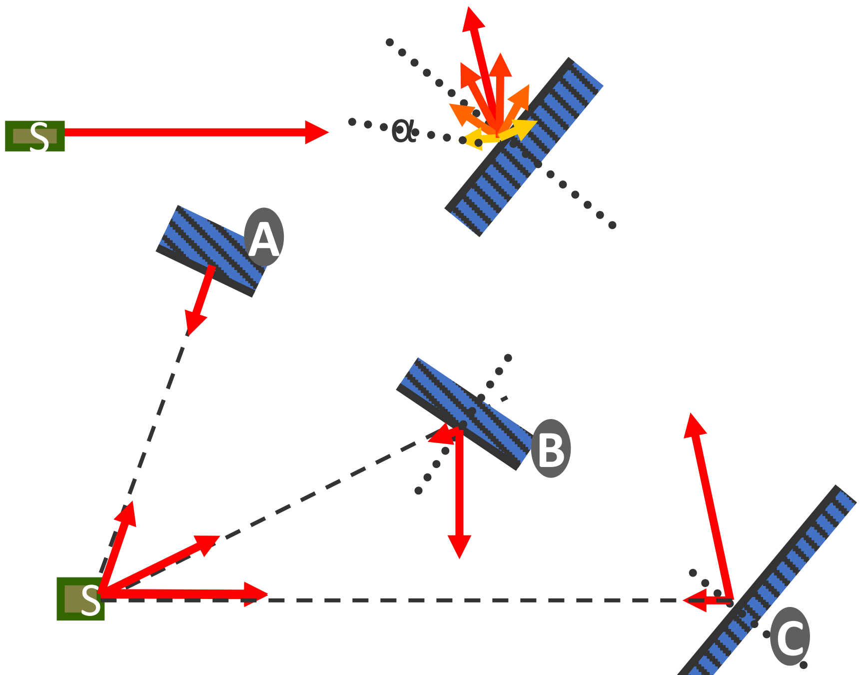
- Infrared (IR) sensors are widely used as proximity sensors and for obstacle avoidance in robotics
- They offer lower cost and faster response times than other type of sensors (i.e., ultrasonic sensors)
- Because of their non-linear behavior and their dependence on the reflectance of surrounding objects, measurements based on the intensity of the back-scattered IR light are often imprecise for ranging purposes.



- IR Sensors work by using a specific light sensor to detect a select light wavelength in the Infra-Red (IR) spectrum.
- By using an LED which produces light at the same wavelength as what the sensor is looking for, you can look at the intensity of the received light.
- When an object is close to the sensor, the light from the LED bounces off the object and into the light sensor.
- This results in a large jump in the intensity, which can be detected using a threshold.

Ultrasonic Sensors

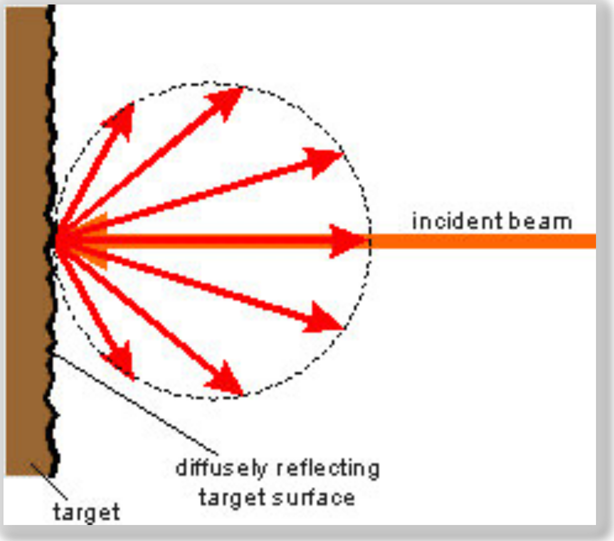
- An Ultrasonic sensor is a device that can measure the distance to an object by using sound waves.
- It measures distance by sending out a sound wave at a specific frequency and listening for that sound wave to bounce back.
- By recording the elapsed time between the sound wave being generated and the sound wave bouncing back, it is possible to calculate the distance between the sonar sensor and the object.

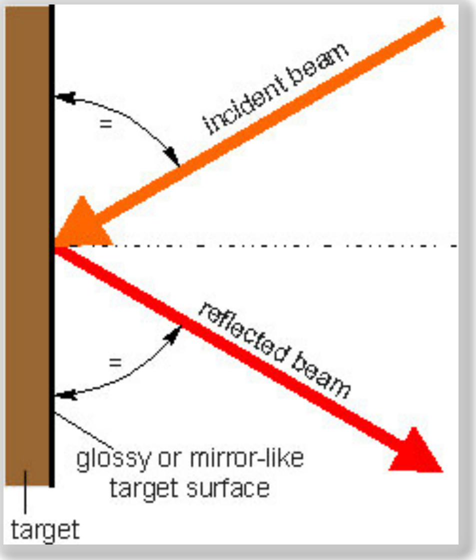


- Shaped or positioned in such a way that the sound wave bounces off the object, but are deflected away from the Ultrasonic sensor.
- The object might be too small to reflect enough of the sound wave back to the sensor to be detected.
- The objects may absorb the sound wave all together (cloth, carpeting, etc.), which means that there is no way for the sensor to detect them accurately.

Laser Sensors

- A Laser sensor is a device that can measure the distance to an object by using a laser beam.
- It measures distance by sending out a laser beam and by calculating the time of flight (TOF).
- It can be used to scan obstacles to grater distances than i.e. ultrasonic sensors

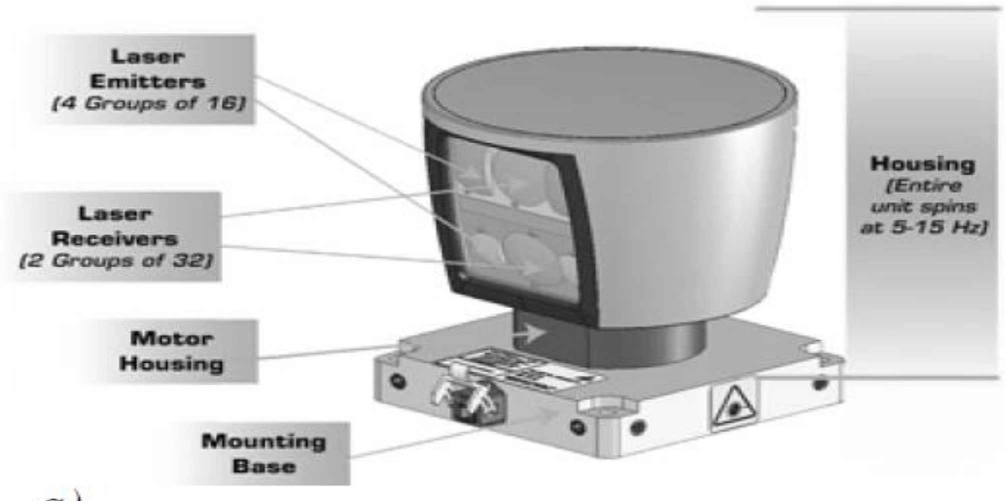


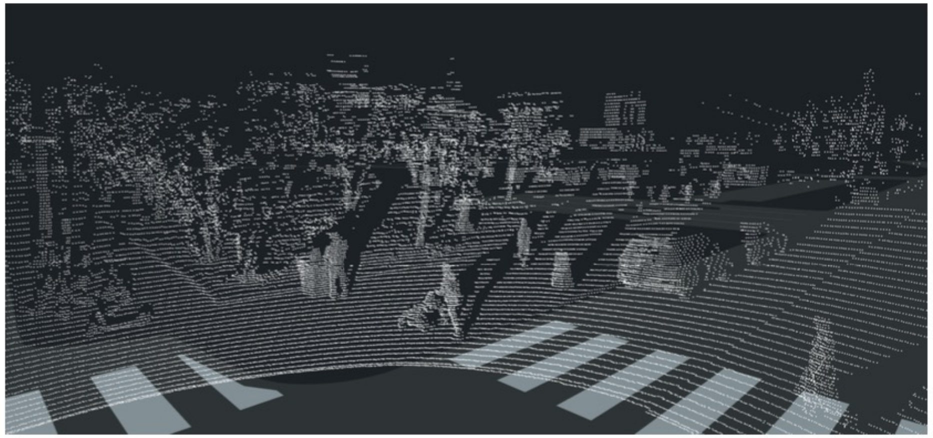


LiDAR

- Light Detection and Ranging (LiDAR) is a remote sensing technology for measuring ranges by using the pulse of a laser. Also known as 3D scanning or laser scanning, it can be used to create digital 3-D representations and map of various environments and ocean surfaces.

- The main component of a LiDAR system is the laser transmitting and receiving systems along with their common or individual optical lens. The laser sends out light pulses of near-infrared wavelength of usually 905 or 1550 nanometers and measure how long it takes for the receiver to detect the reflected pulse. The data processing system combines the direction and calculated distance of each pulse to create a point-cloud representation.

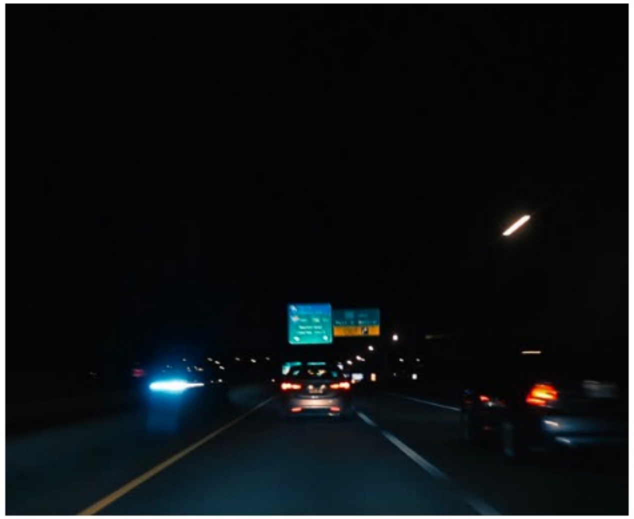




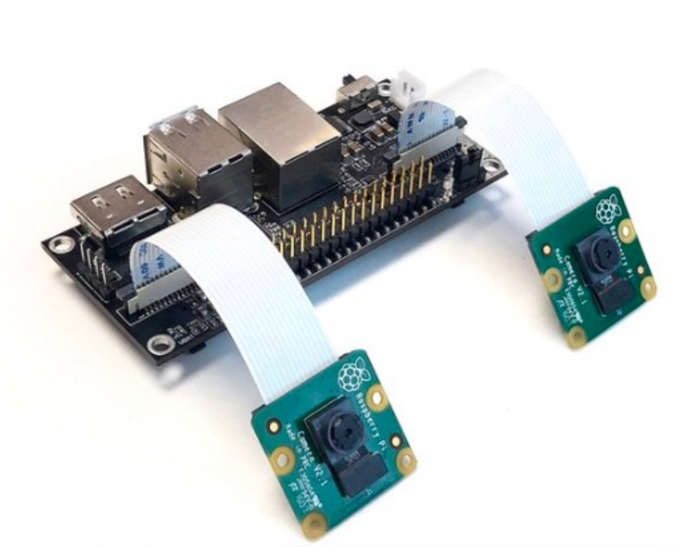
Vision Based Sensors

- Computer Vision provides robots with the capability to passively observe the environment.
  - Stereo vision systems provide complete location information using triangulation.

(a) Camera view during fog

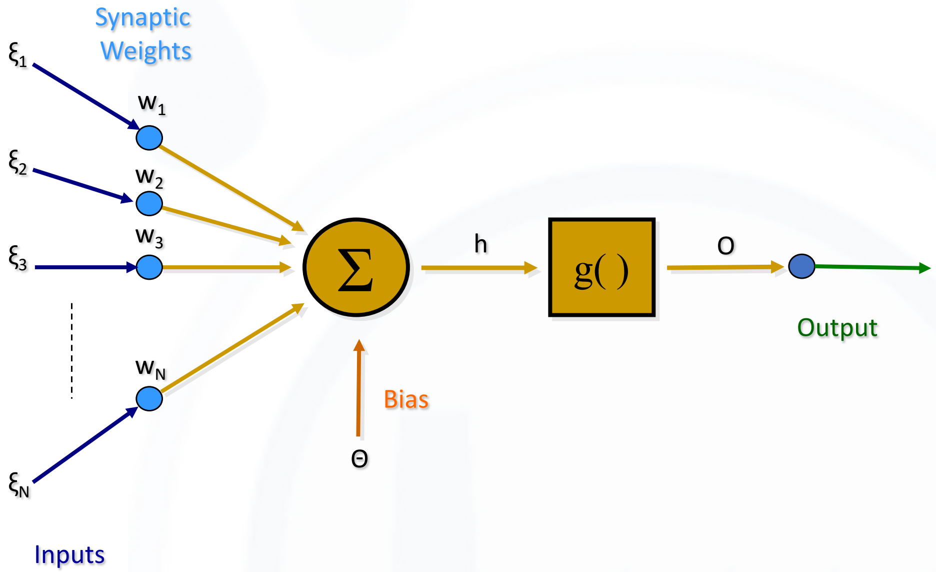


(b) Camera view during night



How can we create fully autonomous robots?

- **Artificial Neural Networks** inspired by the human brain!!!
  - A neural network can be defined as a model of reasoning based on the human brain
  - The brain consists of a densely interconnected set of nerve cells, or basic information-processing units, called neurons
  - Human Brain:
  - – 10 billion neurons
  - – 60 trillion connections, synapses
  - By using multiple neurons simultaneously, the brain can perform its actions much faster than the fastest computers in existence today



Activation : $h = \sum_{k=1}^{N} w_k \xi_k + \theta$

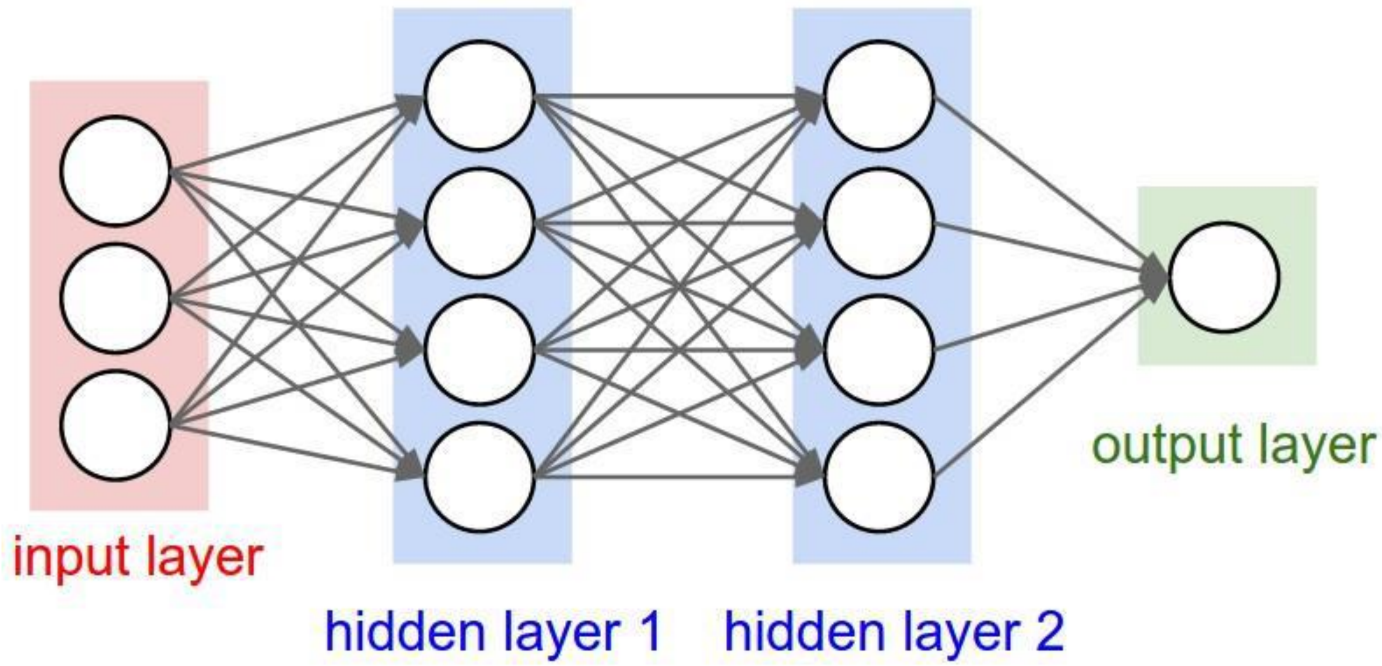
Activation Function $g(\ )$

Output : $O = g(h) = g\left(\sum_{k=1}^{N} w_k \xi_k + \theta\right)$

Train Artificial Neural Networks to do the job…

Forward Pass

How far away are we from the desired target?

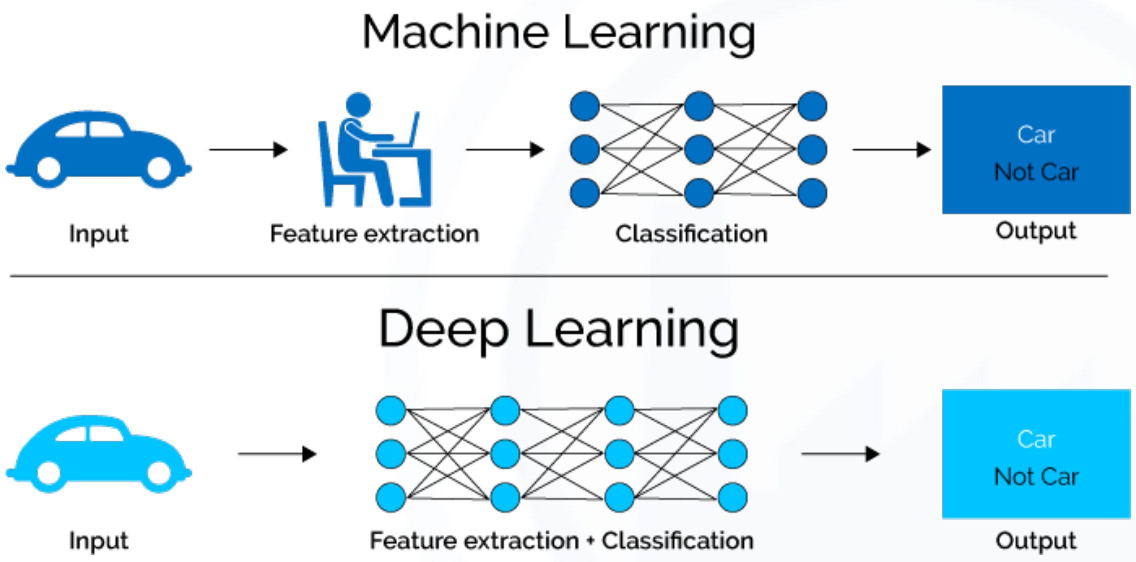


Backward Pass

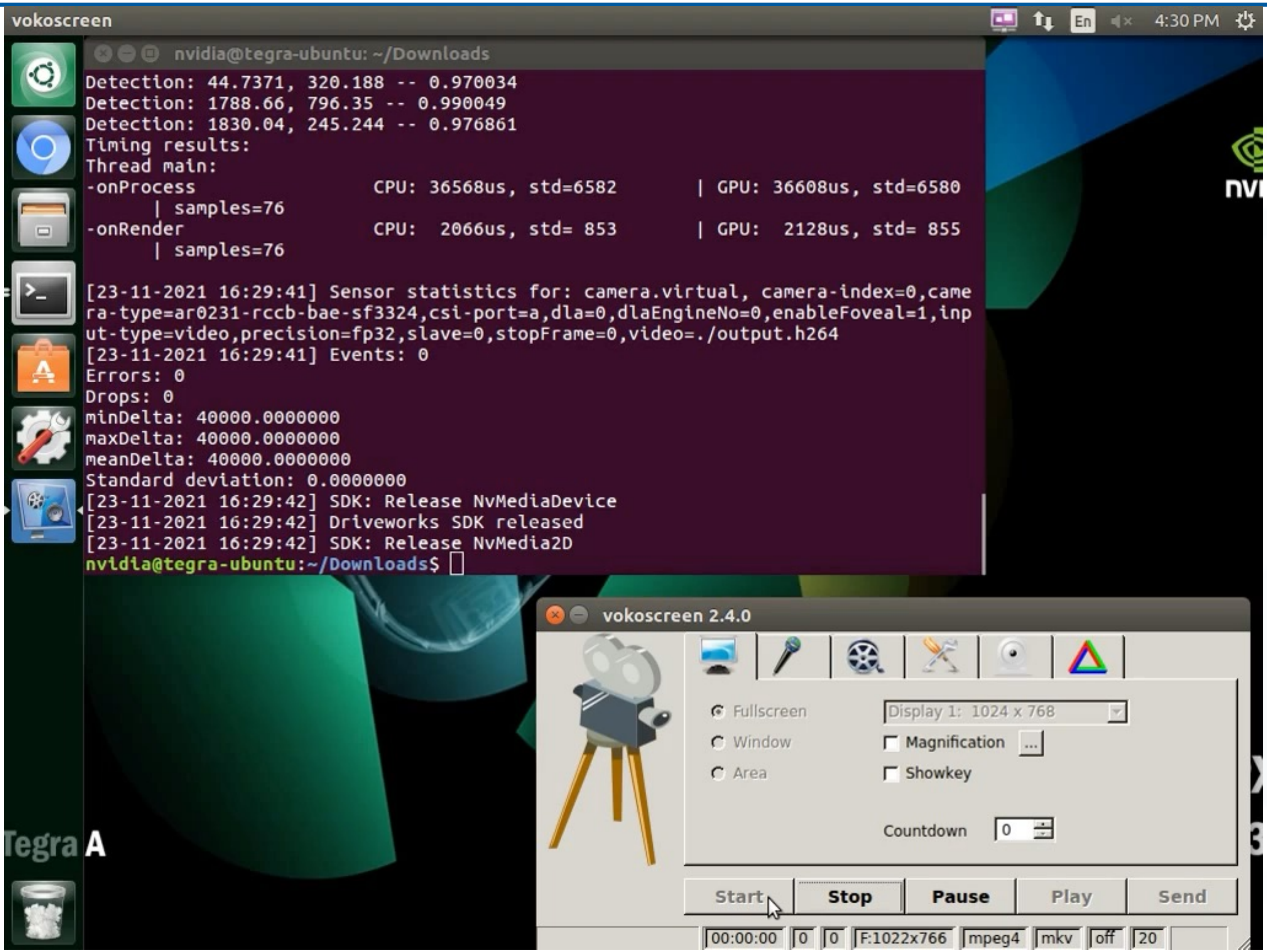
Go back and “tune” the network

A step further, Deep Learning…

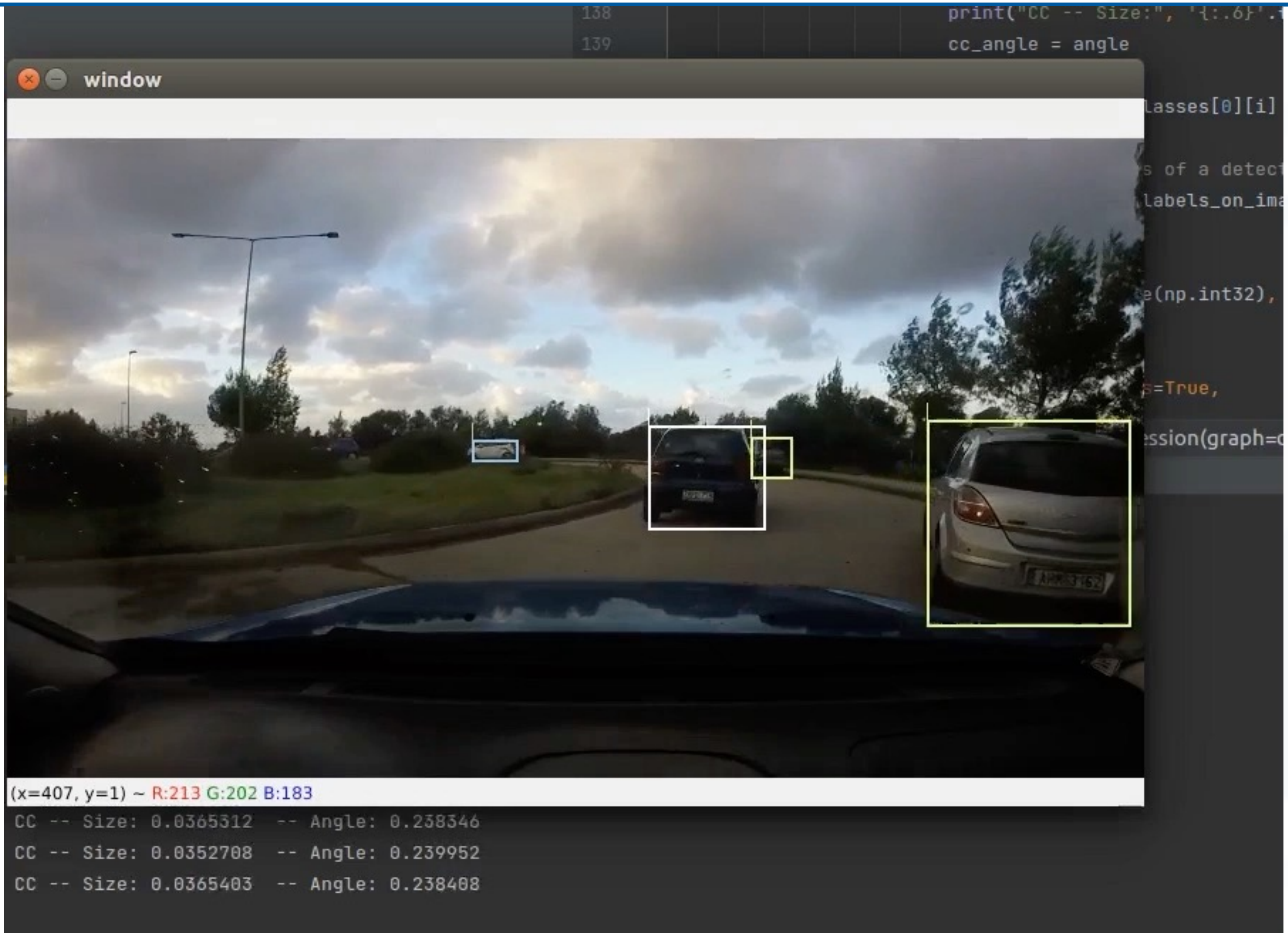
- Learn multiple layers of transformation of inputs, using multi-layer artificial neural networks with many hidden layers stacked one after the other.
- Extract progressively more sophisticated representations.
- It reduces the burden on the programmer to select the features explicitly. It can be used to solve supervised, unsupervised or semi-supervised type of challenges.



Autonomous Robots - Perceiving the environment

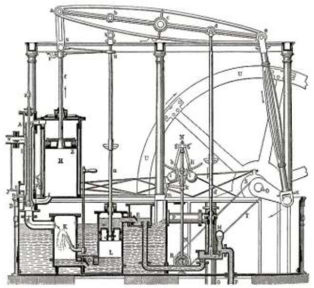


Autonomous Navigation – Tracking Car



Autonomous Navigation – Tracking & Driving a Car

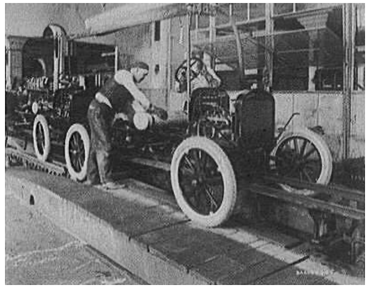
Industry 4.0 – Historical Perspective



1. Industrial revolution
Introducing mechanical production machines powered by water and steam

Industry 1.0

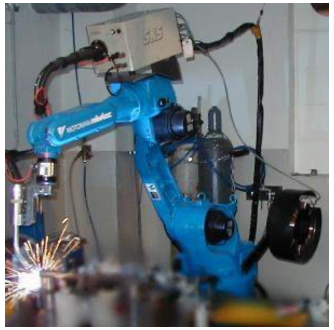
End of the 18th century.



2. Industrial revolution
Introducing mass production lines powered by electric energy

Industry 2.0

Beginning of the 20th century



3. Industrial revolution
Through the use of electronics and IT further progression in autonomous production

Industry 3.0

Beginning of the 70th

4. Industrial revolution
Based on cyber-physical-systems

Industry 4.0

Today

Level of complexity

Source: DFKI/Bauer IAO

Industry 4.0[1]

- A collective term for technologies and concepts of value chain organization. Based on the technological concepts of ***cyber-physical systems***, the ***Internet of Things*** and the ***Internet of Services***, it facilitates the vision of the Smart Factory. Within the modular structured Smart Factories of Industry 4.0, cyber-physical systems monitor physical processes, create a virtual copy of the physical world and make decentralized decisions. Over the Internet of Things, Cyber-physical systems communicate & cooperate with each other & humans in real time. Via the Internet of Services, both internal & cross-organizational services are offered & utilized by participants of the value chain.

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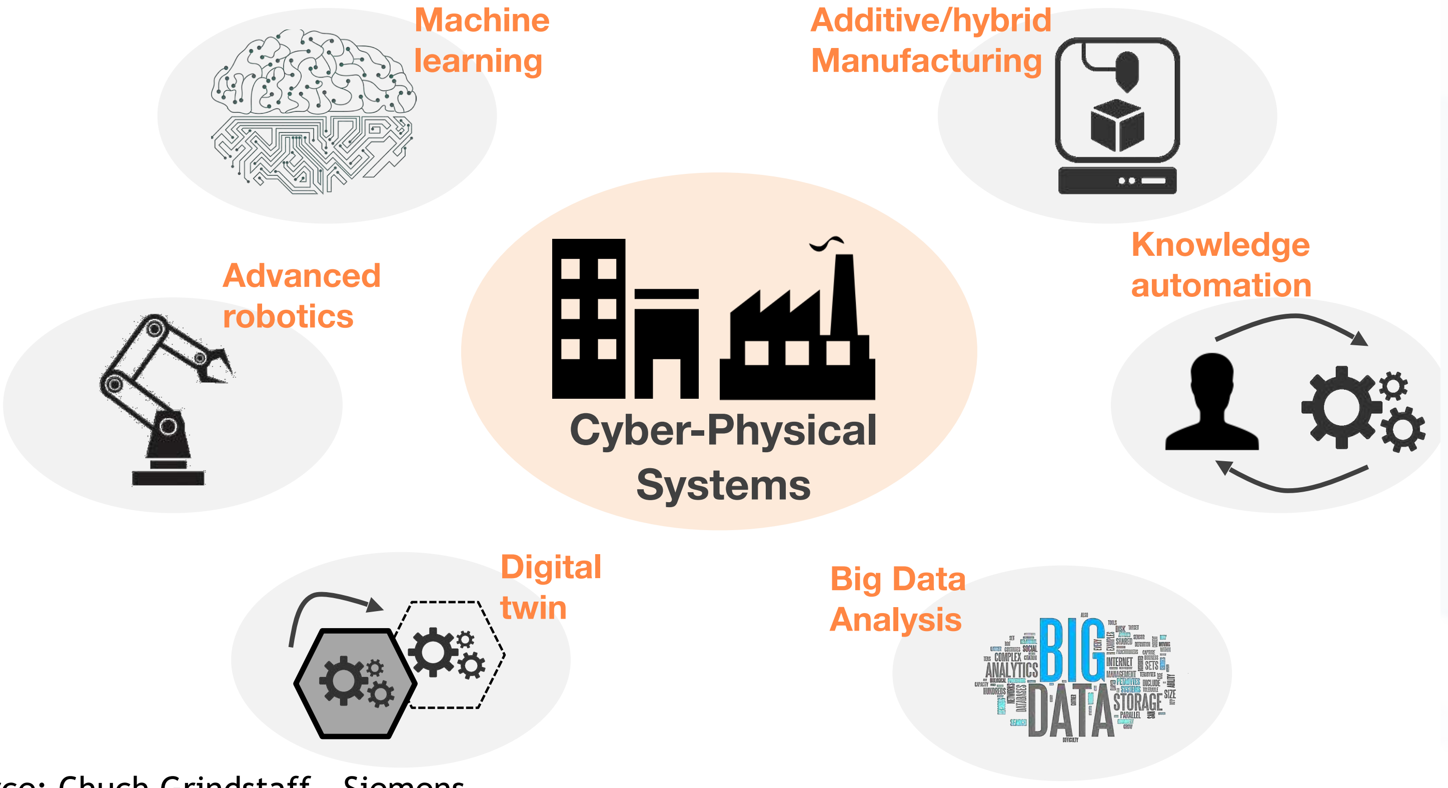
[1] Industry 4.0: Why it matters? Presentation by EY

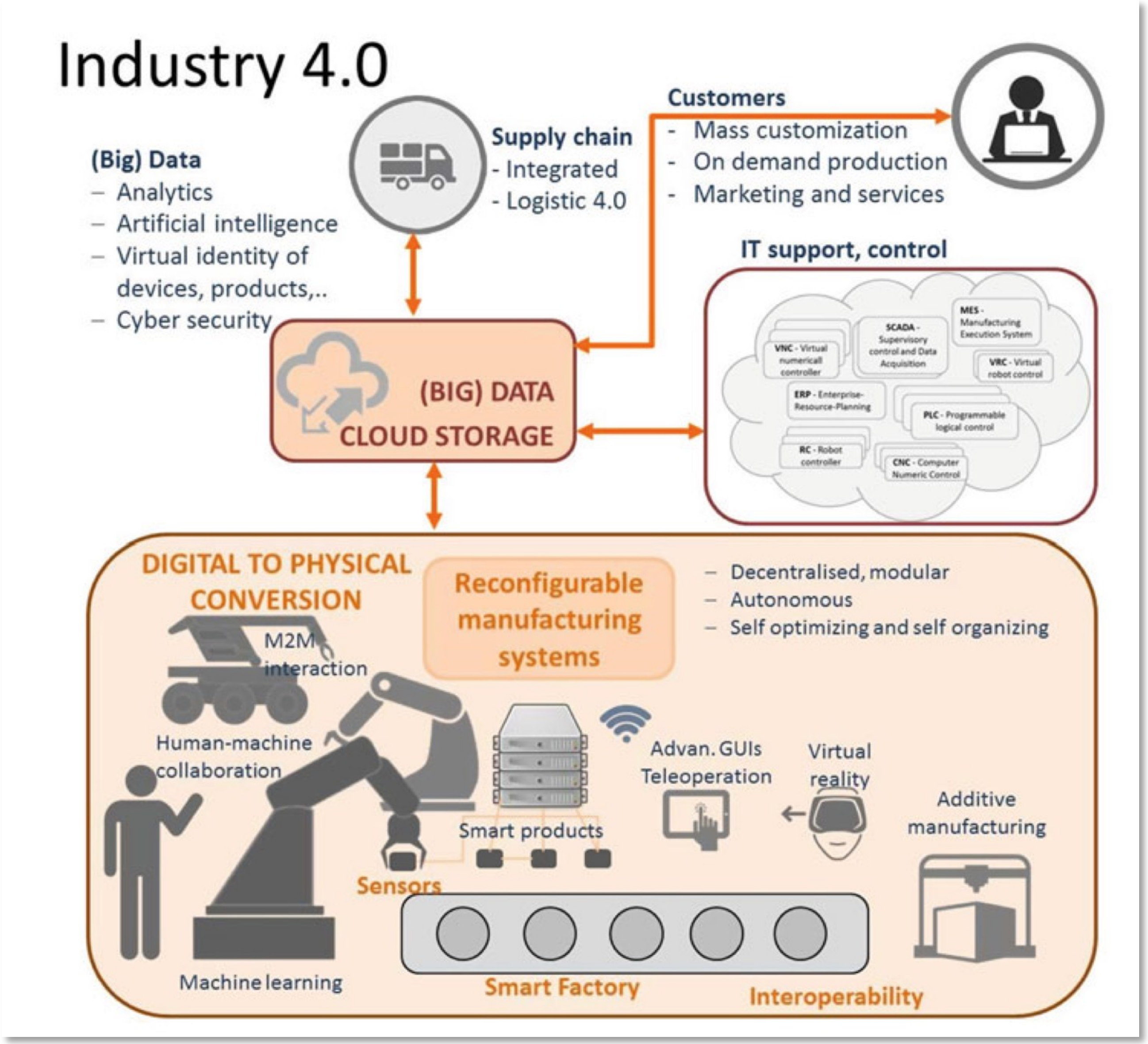
Industry 4.0 – Cyber Physical Systems

- A **cyber-physical system (CPS)** is a system of collaborating computational elements controlling physical entities. CPS are physical and engineered systems whose operations are monitored, coordinated, controlled and integrated by a computing and communication core. They allow us to add capabilities to physical systems by merging computing and communication with physical processes.



Source: Chuch Grindstaff - Siemens

Industry 4.0 Ecosystem



- ❑ Mobile Robots (AGVs, autonomous, semi-autonomous).
- ❑ Robot Swarms
- ❑ Manipulators
- ❑ Collaborative robots
- ❑ Unmanned Aerial Robots
- ❑ Custom robots
- ❑ Advanced sensors
- ❑ ....

Source: Ashwin Misra, Anuj Agrawal, and Vihaan Misra, Robotics in Industry 4.0, *in Handbook of Smart Materials, Technologies, and Devices*, C. M. Hussain, P. Di Sia (eds.), Springer Nature Switzerland. https://doi.org/10.1007/978-3-030-58675-1_68-1

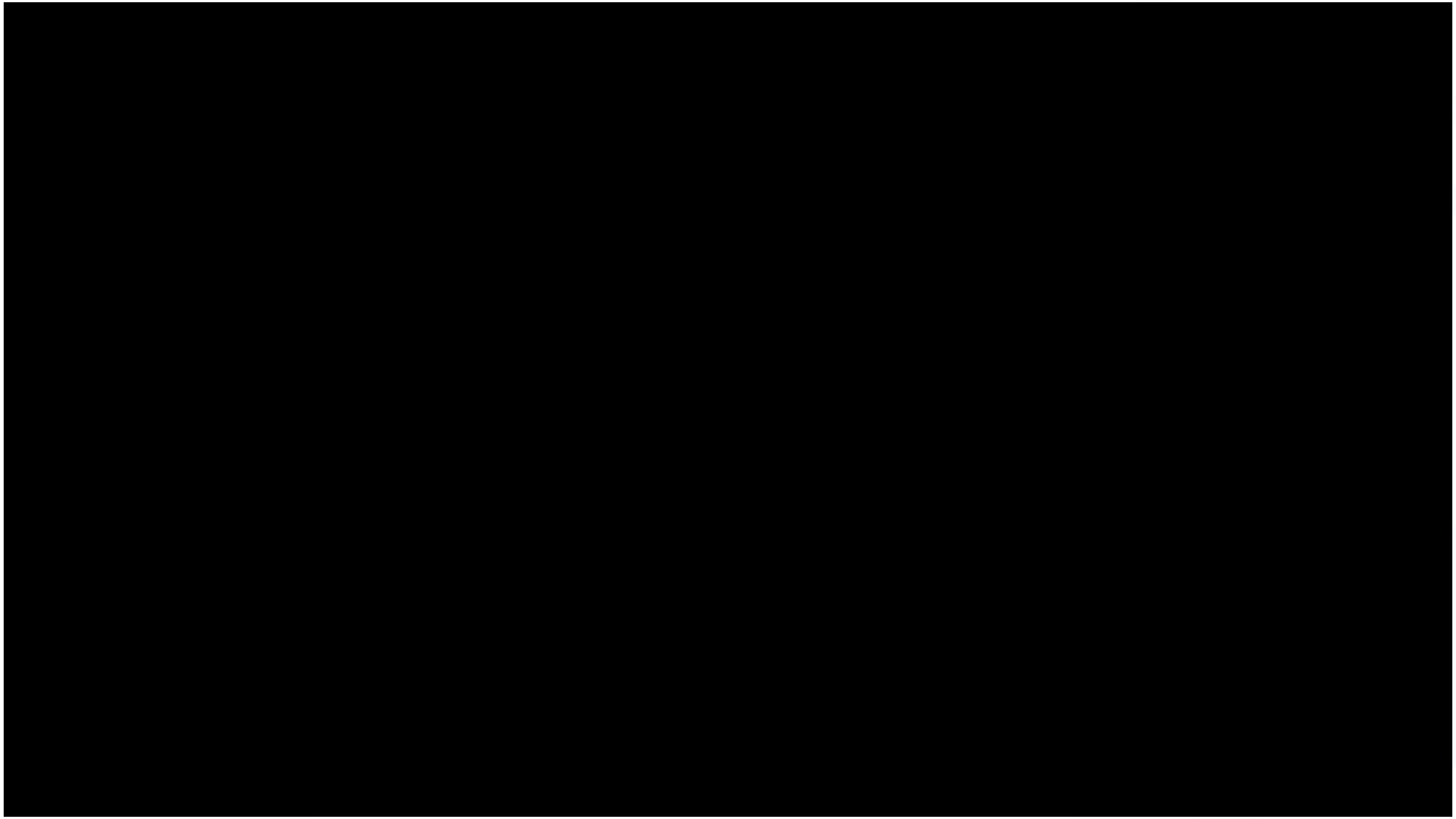
Industry 4.0 – Robots & Humans cooperate and act as colleagues…

- A **collaborative robot**, also known as a **cobot**, is an industrial robot that can safely operate alongside humans in a shared workspace. In contrast, autonomous robots, in industry, are hard-coded to repeatedly perform one task, work independently and remain stationary.

- The wide use of robots, cobots and mechatronics in the Industry 4.0 made people skeptical, since robotization is the key point, which may either turn humans obsolete in the industrial environment or in the best-case scenario will make robots a necessity for them.

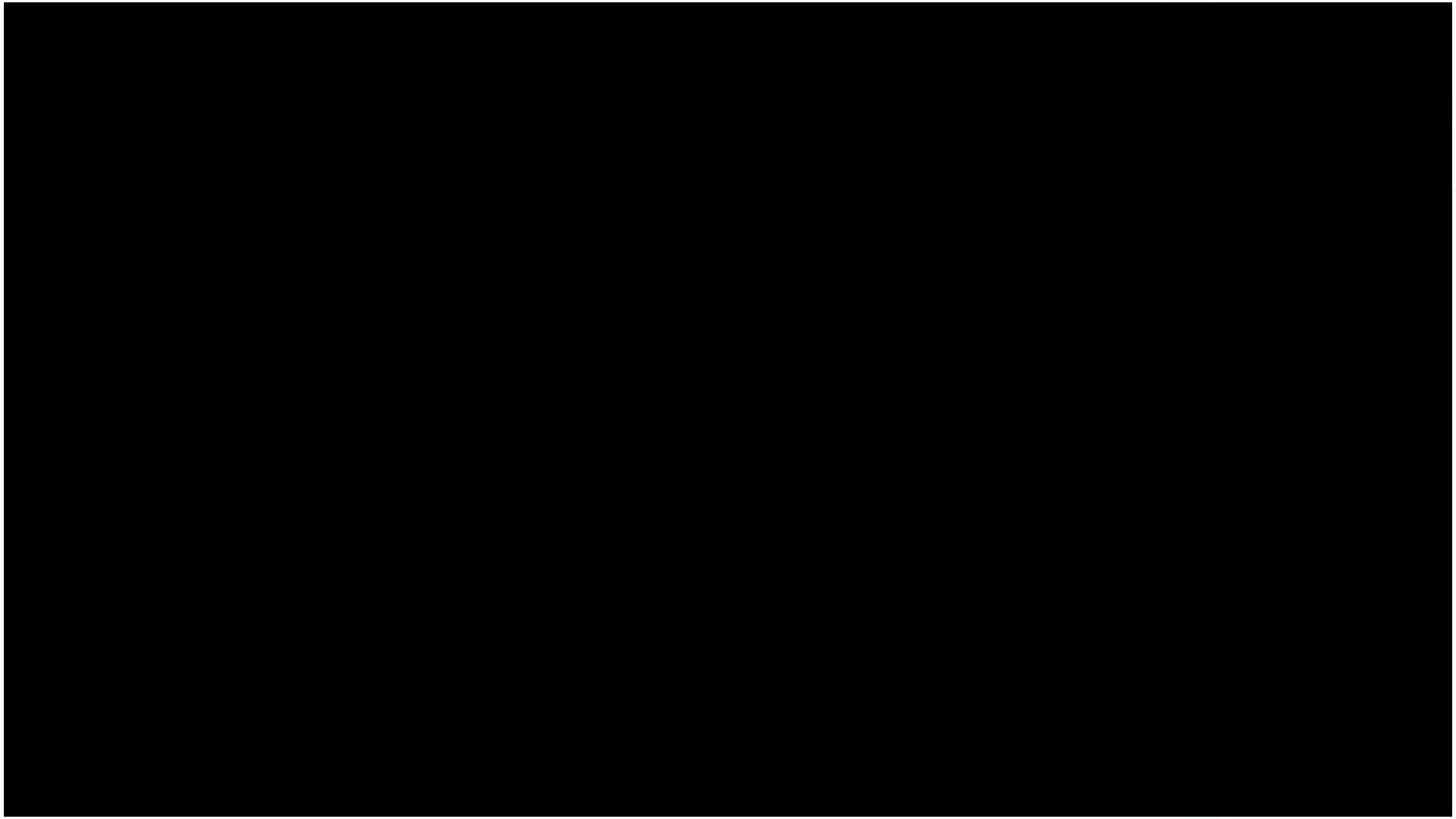
- Humans want robots to make their lives easier and safer, yet they lack trust in them.

AGVs in Industry 4.0



Source: Kuka – Robots & Automation [link]

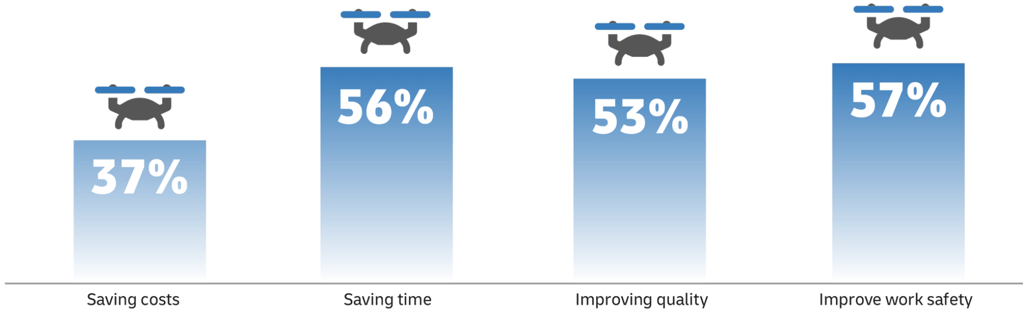
Robot Swarms in Industry 4.0



Source: Hellenic Post [link]

UAVs in Industry 4.0

Why adopting drones in industry?



Source: Drone Industry Insights

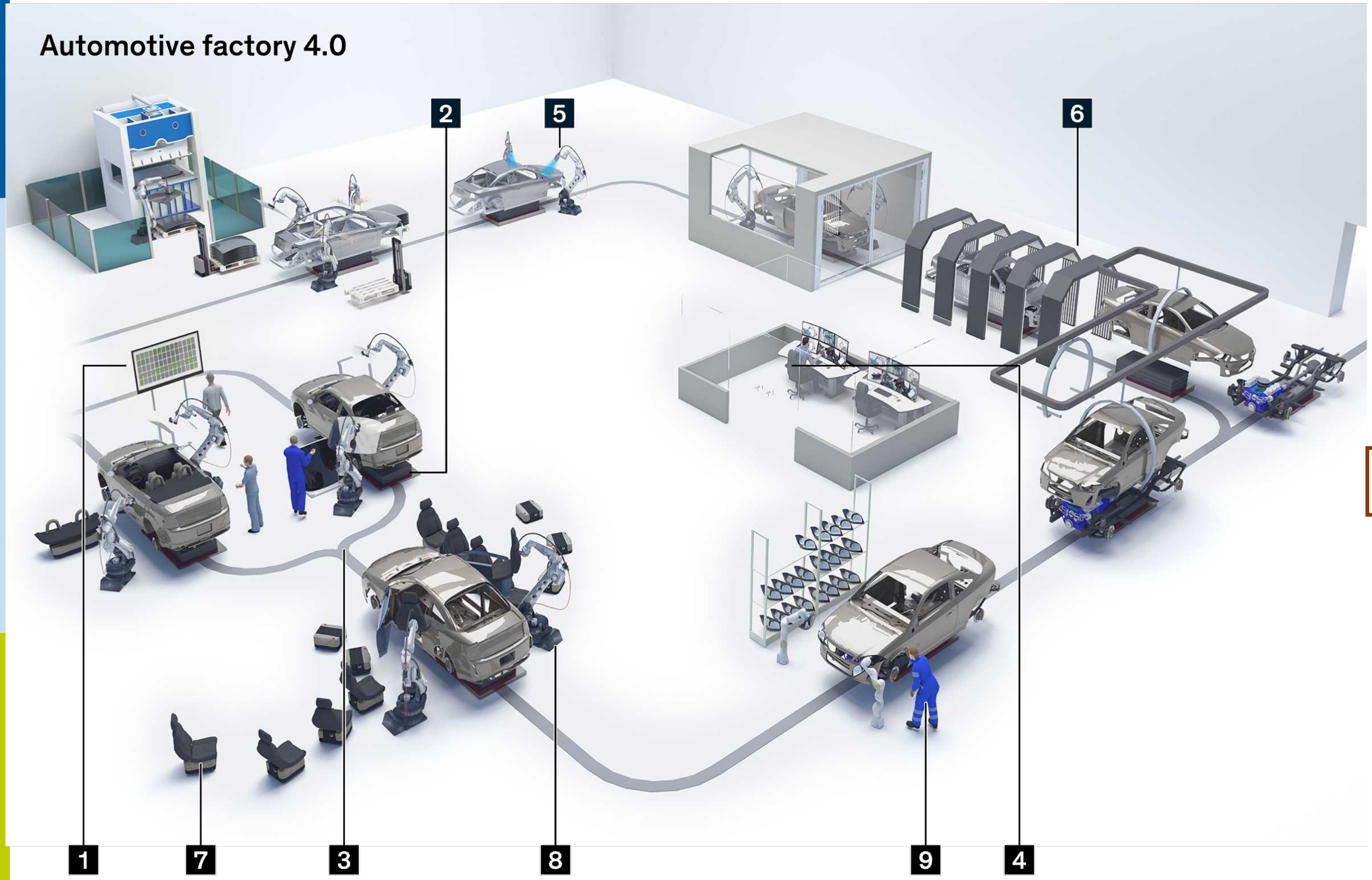
- Quality Control & Monitoring
- Transportation & Logistics
- Inspection & Maintenance
- Inventory Monitoring

Source: DHL

Source: Audi AG.

Top left: RPA md4-200 in inspection services (source: microdrones) : Top Right: Power lines. Bottom left: Thermographic surveys and defect analysis of photovoltaic cells (UAV vision).Middle right: unmanned visual inspection of flare stacks source: Unmanned Systems Tech .Bottom right: Pipelines.

Case study: Automotive Factory 4.0 & the role of robots



Flexible routing, scheduling, load balancing, and performance management

1. Artificial intelligence (AI)-based optimized scheduling (eg, matching of skills, experience)

2. Primary material flow through AGV[1] platforms

3. AI-supported load balancing, based on realtime and historical data

4. Digital performance management based on near real-time data

[1]Automated guided vehicles.

Closed control loops through sensor-based in-line quality inspection

5. Early detection of process parameter deviation and rapid correction, reducing scrap (eg, using scanner-based body shop inspection)

6. Camera-based quality inspection improves defect identification and enables targeted rework

Extension of automation to final and pre-assembly

7. Automated line replenishments and parts delivery through AGVs

8. Extended use of industrial robots (eg, through machine vision guidance)

9. Collaborative unfenced in-line robots

Additional value drivers

Value capture typically only for selected areas: predictive maintenance for production machines and tools, warehouse automation, automated high capacity battery cell and pack handling

Source: McKinsey & Company, Capturing value at scale in discrete manufacturing with industry 4.0. link

Thank you!

Questions?