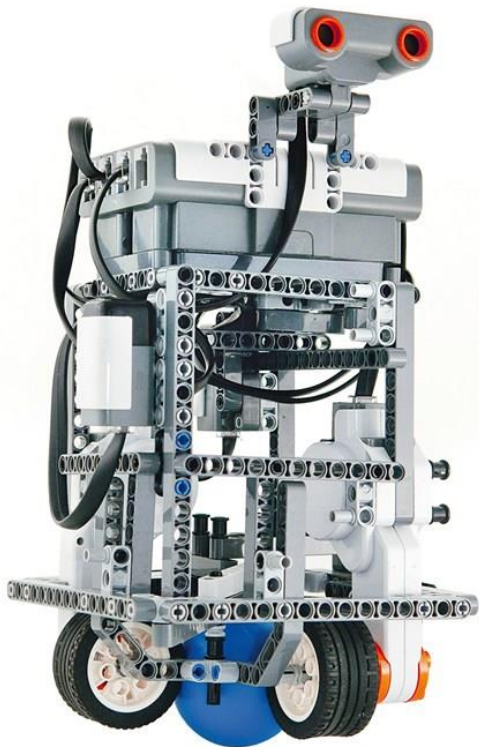


# **CSE444: Introduction to Robotics**

## **Lesson 1a: Introduction**

Summer 2019





# What is a robot?



# A Robot is:

An electromechanical device that is:

- Reprogrammable
- Multifunctional
- Sensible for environment

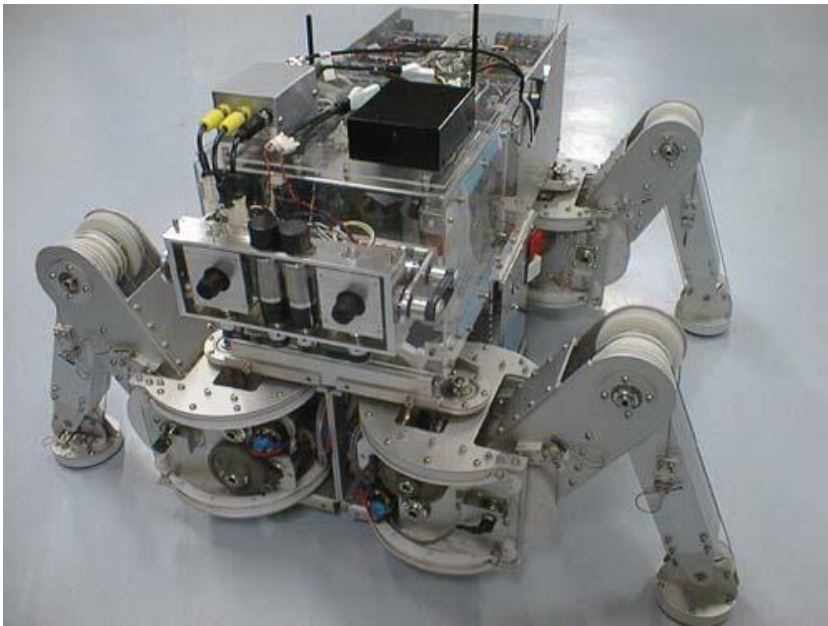
# What is a Robot: I

Manipulator

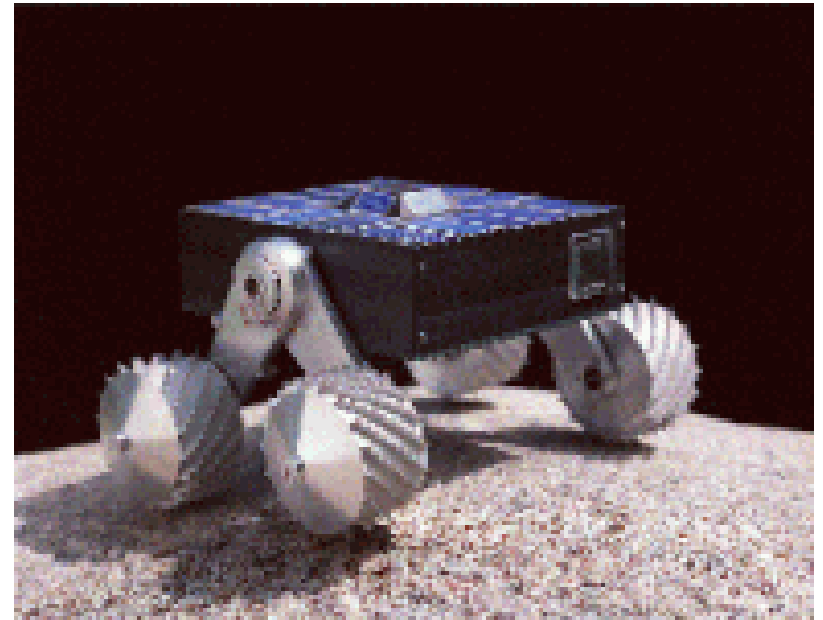


# What is a Robot: II

Legged Robot



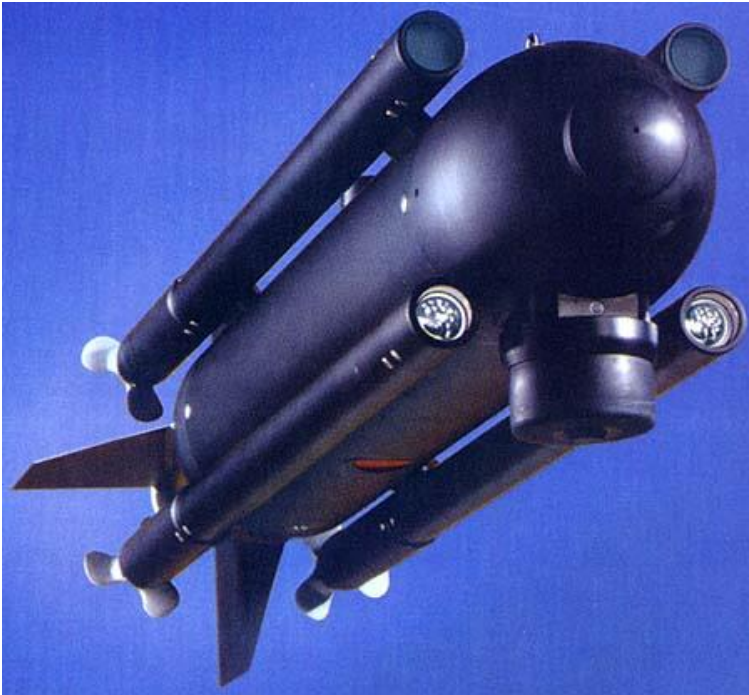
Wheeled Robot





# What is a Robot: III

Autonomous Underwater Vehicle



Unmanned Aerial Vehicle





# What Can Robots Do: I

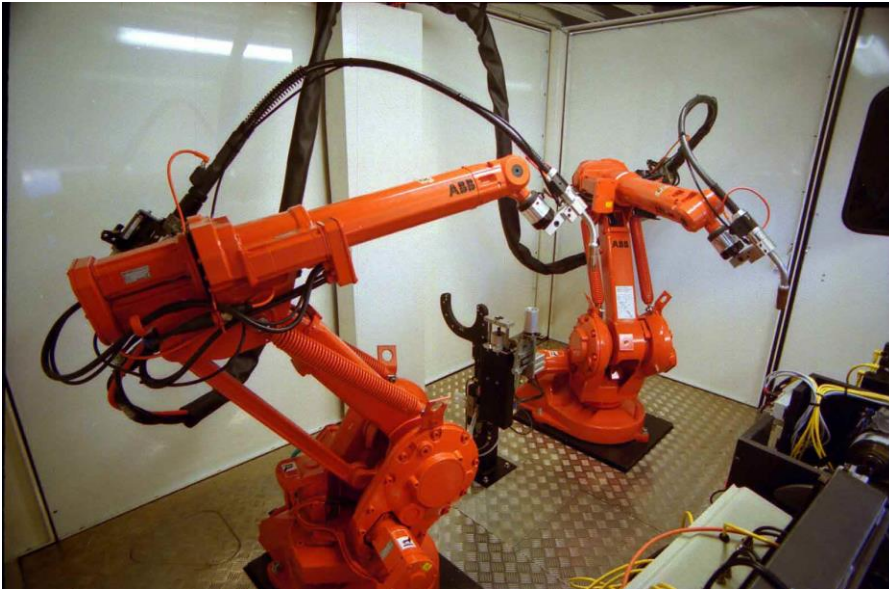


Jobs that are dangerous for humans

## **Decontaminating Robot**

Cleaning the main circulating pump housing in the nuclear power plant

# What Can Robots Do: II



Welding Robot

Repetitive jobs that are boring, stressful, or labor-intensive for humans

# Why Robotics?

shift in robot numbers...!



## Practice



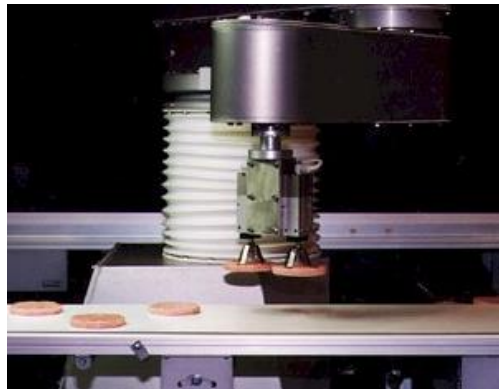
welding



assembly



pumping gas



packaging



eating automobiles



dancing

## Promise



# Current Robot Arm Applications

## Manufacturing

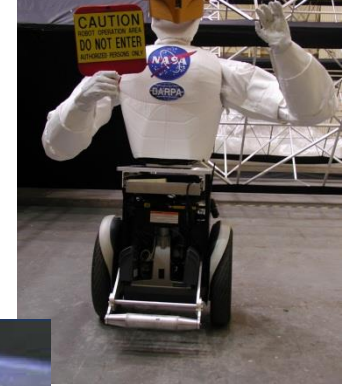
- Engineered environment
- Repeated motion



**1 million arms in operation  
worldwide**

[http://en.wikipedia.org/wiki/Industrial\\_robot](http://en.wikipedia.org/wiki/Industrial_robot)

# Emerging Robotics Applications



**Space** - in-orbit, repair and maintenance, planetary exploration anthropomorphic design facilitates collaboration with humans



**Basic Science** - computational models of cognitive systems, task learning, human interfaces



**Health** - clinical applications, "aging-in-place," physical and cognitive prosthetics in assisted-living facilities

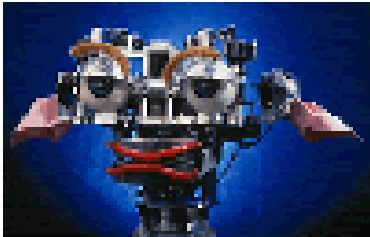
**Military or Hazardous** - supply chain and logistics support, refueling, bomb disposal, toxic/radioactive cleanup



**No or few robots currently operate reliably in these**

kismet

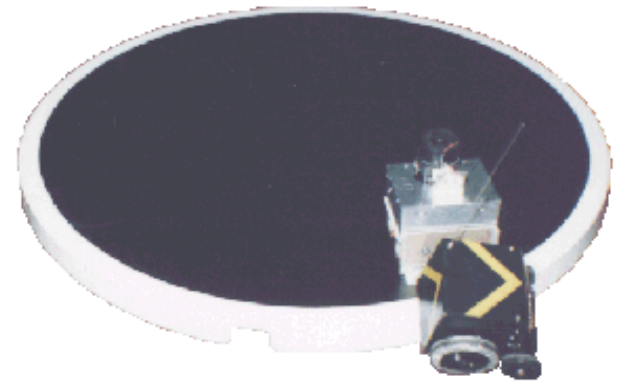
# Why Robotics?



Sony Aibo dogs - had to LEARN to run

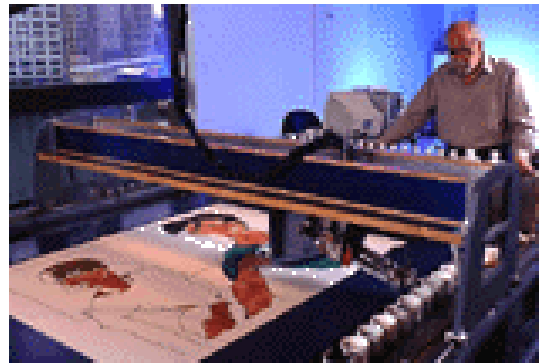


Vibrant field



other competitions

Harold Cohen's Aaron





# Why Robotics?

A window to the soul...

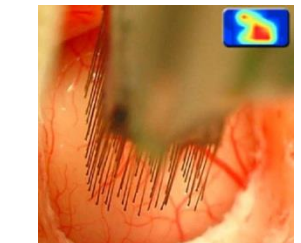


Rodney Brooks's Cog

Photo © Sam Ogden



MIT's robotic fish with an unusual actuator!



Monkey/machine interface at the Univ. of Pittsburgh

*Advances in AI and in Robotics are one and the same.*

AI-complete...

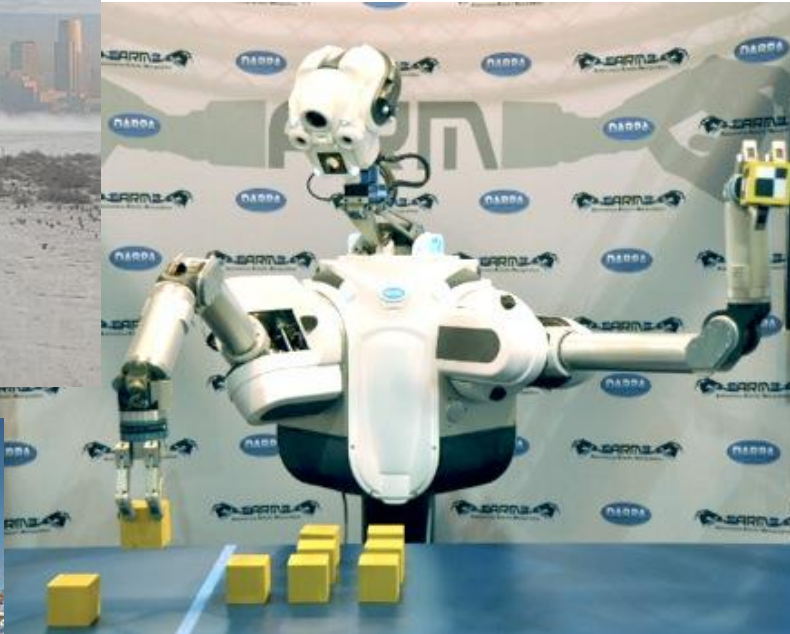


# Robotics challenges

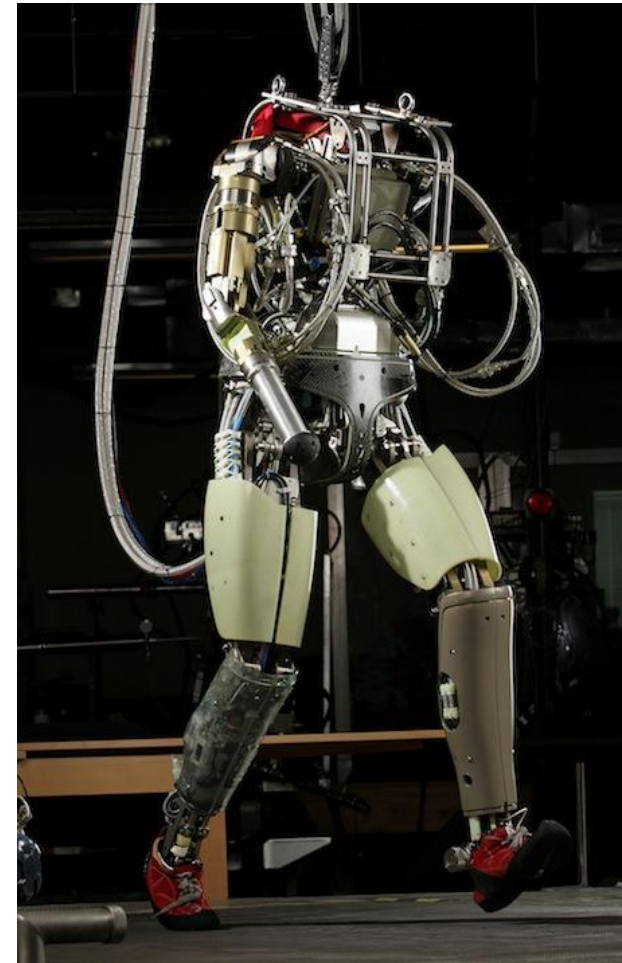
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**Navigation '05**



**Manipulation '11-14**



**Humanoids '12-15**

# DARPA Robotics Challenge



# What Can Robots Do: III



The SCRUBMATE Robot

Manual tasks that human don't want to do

# History of Robotics - The Origins of Robots

**≈250 B.C.** - [Ctesibius](#), an ancient Greek engineer and mathematician, invented a water clock which was the most accurate for nearly 2000 years.

**≈60 A.D.** – [Hero of Alexandria](#) designs the first automated programmable machine. These 'Automata' were made from a container of gradually releasing sand connected to a spindle via a string. By using different configurations of these pulleys, it was possible to repeatably move a statue on a pre-defined path.

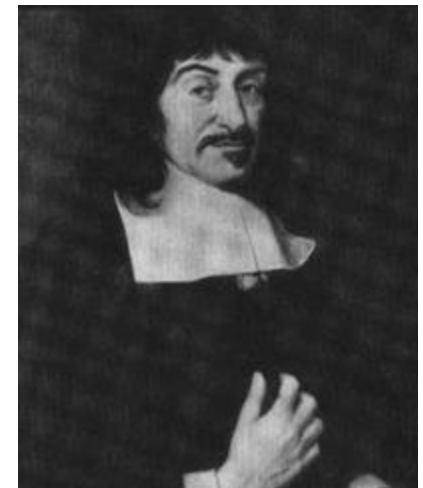


# History of Robotics - The Origins of Robots

≈ **1250** - Bishop **Albertus Magnus** holds banquet at which guests were served by metal attendants. Upon seeing this, Saint Thomas Aquinas smashed the attendants to bits and called the bishop a sorcerer.



**1640** - **Descartes** builds a female automaton which he calls “Ma fille Francine.” She accompanied Descartes on a voyage and was thrown overboard by the captain, who thought she was the work of Satan.



# History of Robotics - The Origins of Robots

**1738** - [Jacques de Vaucanson](#) builds a mechanical duck made of more than 4,000 parts. The duck could quack, bathe, drink water, eat grain, digest it and void it. Whereabouts of the duck are unknown today.



**1805** - Doll, made by [Maillardet](#), that wrote in either French or English and could draw landscapes.



# History of Robotics - The Origins of Robots

**1898** - The first radio-controlled submersible boat was invented by [Nikola Tesla](#).

**1921** - The term "**robot**" was first used in 1920 in a play called "R.U.R." Or "*Rossum's universal robots*" by the Czech writer [Karel Capek](#). The plot was simple: man makes robot then robot kills man! Many movies that followed continued to show robots as harmful, menacing machines. *Robot* comes from the Czech word *robota*, which means "servitude, forced labor."

The logo for "Robotics" features the word in a bold, black, sans-serif font, slanted upwards to the right. The letter 'o' in "Robotics" is replaced by a stylized red robot head with a white visor and a small antenna.



# History of Robotics - The Origins of Robots

Robotics was first introduced into our vocabulary by Czech playwright Karel Capek in his 1920's play **Rossum's Universal Robots**.

The word "robota" in Czech means simply work. Robots as machines that resemble people, work tirelessly, and revolt against their creators. .



Karel Capek

The same myth/concept is found in many books/movies today:

"Terminator", "Star-Wars" series.

Mary Shelley's 1818 Frankenstein.

Frankenstein & The Borg are examples of "**cybernetic organisms**".

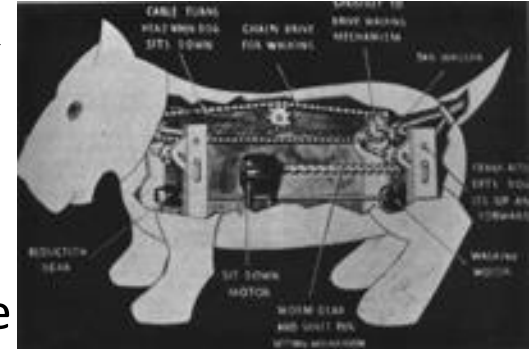
# History of Robotics

**1940** - Sparko, the [Westinghouse](#) dog, uses both mechanical and electrical components.

**1941** - Isaac Asimov introduced the word 'Robotics' in the science fiction short story 'Liar!'

**1948** - [William Grey Walter](#) builds Elmer and Elsie, two of the earliest autonomous robots with the appearance of turtles. The robots used simple rules to produce complex behaviors.

**Cybernetics** is a discipline that was created in the late 1940's by Norbert Wiener, combining feedback control theory, information sciences and biology to try to explain the common principles of control and communications in both animals and machines.



# History of Robotics

**1950`s** - Computer technology advances and control machinery is developed.

*Questions Arise: Is the computer an immobile robot?*

**1954** - The first silicon transistor was produced by Texas Instruments.

**1954** – **George Devol** replaced the slave manipulator in a teleoperator with the programmability of the CNC controller, thus creating the first “industrial robot”, called the “Programmable Article Transfer Device”.

# History of Robotics

**1955** – The Darmouth Summer Research Conference marks the birth of AI. [Marvin Minsky](#), from the AI lab at MIT defines an intelligent machine as one that would tend to “build up within itself an abstract model of the environment in which it is placed. If it were given a problem, it could first explore solutions within the internal abstract model of the environment and then attempt external experiments”. This approach dominated robotics research for the next 30 years.

**1956** - Researchers aim to combine “perceptual and problem-solving capabilities,” using computers, cameras, and touch sensors. The idea is to study the types of intelligent actions these robots are capable of. A new discipline is born: [A.I.](#)

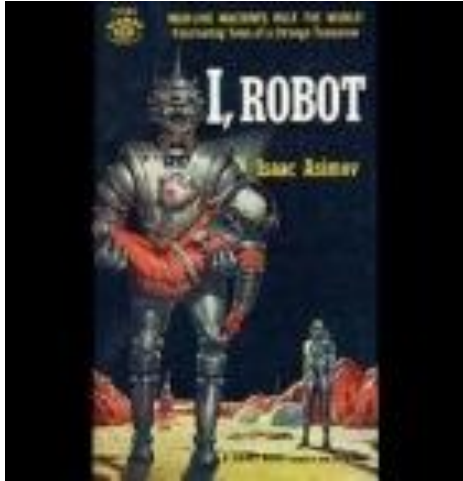
# History of Robotics

**1956** - [Joseph Engleberger](#), a Columbia physics student buys the rights to Devol's robot and founds the Unimation Company.

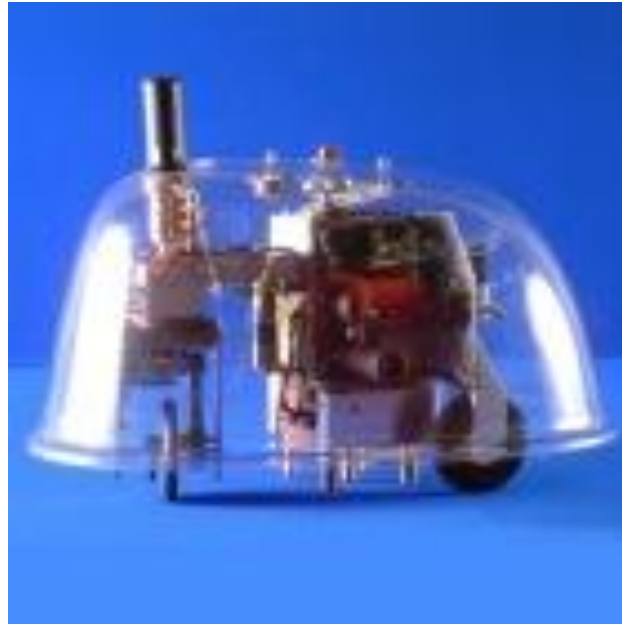
**1956** - [George Devol](#) applied for a patent for the first programmable robot, later named 'Unimate'.

**1957** - Launch of the first artificial satellite, [Sputnik 1](#).

# History of Robotics



I, Robot



Turtle robot



Sputnik I

# History of Robotics

- **1960`s** - Industrial Robots created. Robotic Industries Association states that an *“industrial robot is a re-programmable, multifunctional manipulator designed to move materials, parts, tools, or specialized devices through variable programmed motions to perform a variety of tasks”*.



*Robot Institute of America, 1979*



# History of Robotics

- **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. The Unimate robot was an innovative mechanical design based on a multi-degree of freedom cantilever beam. The beam flexibility presented challenges for control. Hydraulic actuation was eventually used to alleviate precision problems.
- **1962 – 1963** – The introduction of **sensors** is seen as a way to enhance the operation of robots. This includes force sensing for stacking blocks (Ernst, 1961), vision system for binary decision for presence of obstacles in the environment (McCarthy 1963), pressure sensors for grasping (Tomovic and Boni, 1962). Robot interaction with an unstructured environment at MIT's AI lab (Man and Computer – MAC project).

# History of Robotics

- **1965** - [Gordon E. Moore](#) introduces the concept '[Moore's law](#)', which predicts the number of components on a single chip would double every two years.
- **1966** – 1968 '[Shakey](#)', a mobile robot is developed by SRI (Stanford Research Institute). 'Shakey' was capable of planning, route-finding and moving objects. It was placed in a special room with specially colored objects. A vision system would recognize objects and pushed objects according to a plan. This planning software was STRIPS, and it maintained and updated a world model. The robot had pan/tilt and focus for the camera, and bump sensors.
- **1968** – Kawasaki Heavy Industries in Japan acquires a license for Unimate.
- **1969** - The [Apollo 11 mission](#), puts the first man on the moon. Landing was made inside the [Lunar Module 'Eagle'](#).

# History of Robotics



Unimate 1



Moon Walk



Shakey

# History of Robotics

- **1970** - [Luna 17](#) lands on the moon, carrying the roving remote-controlled robot, [Lunokhod 1](#).
- **1971** - [Intel](#) introduce the first commercially available microprocessor, the [4004](#).
- **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](#).

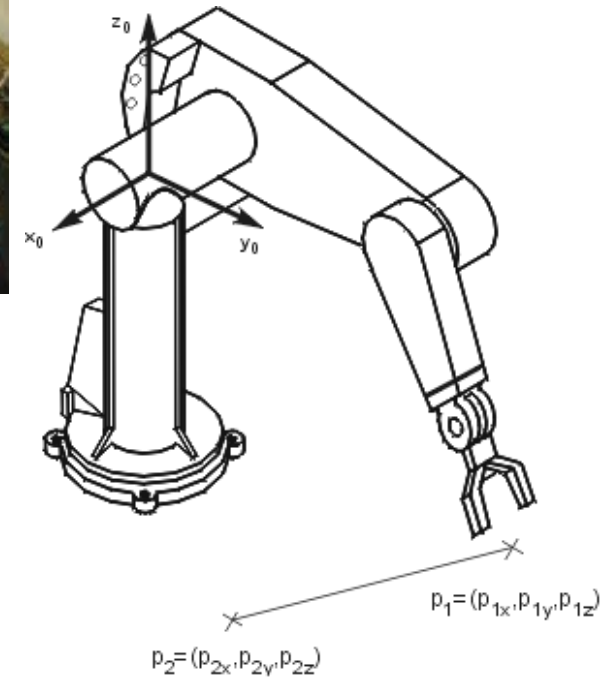
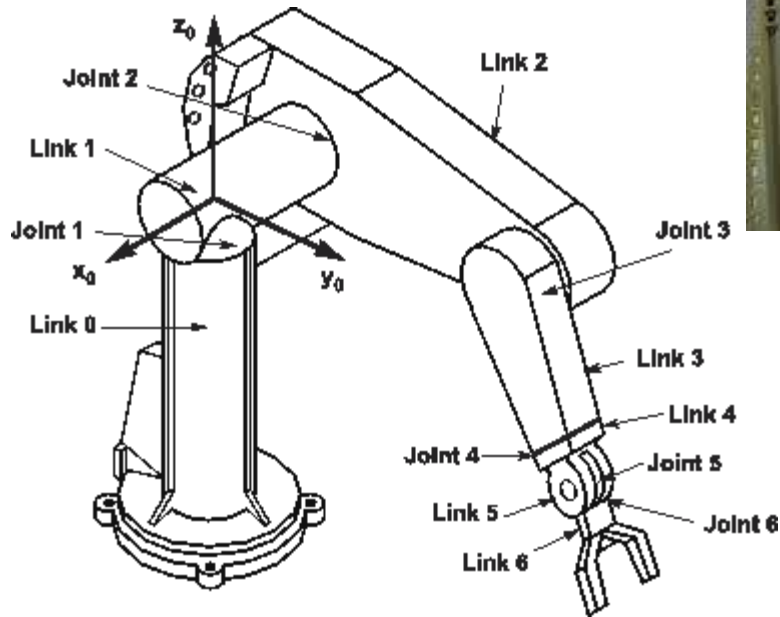
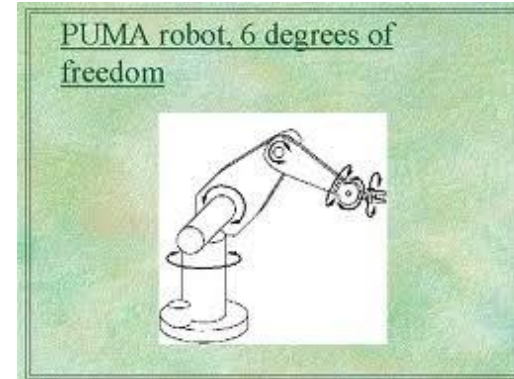
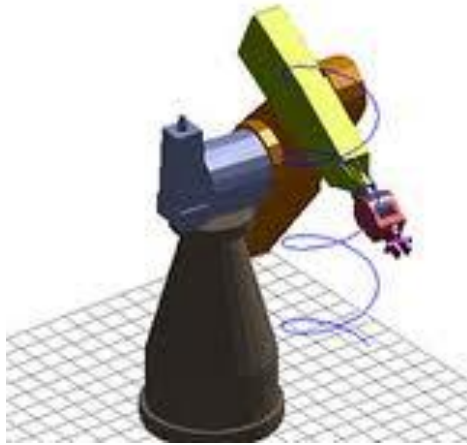
# History of Robotics

- **1977** – Development of mobile robot Hilaire at Laboratoire d'Automatique et d'Analyse des Systemes (LAAS) in Toulouse, France. This mobile robot had three wheels and it is still in use.

## *Two famous robots:*

- **1978- Puma** (Programmable Universal Machine for Assembly), by Unimation.
- **1979 - SCARA** (Selective Compliant Articulated Robot for Assembly) introduced in Japan and the US (by Adept Technologies).

# History of Robotics - PUMA





# History of Robotics - SCARA

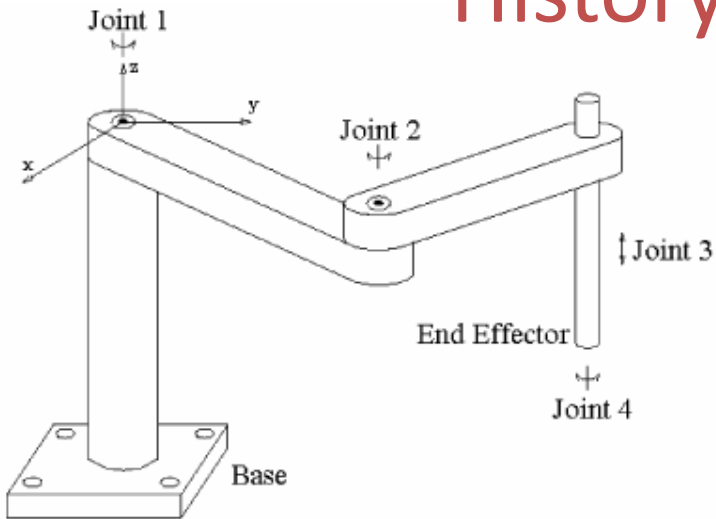
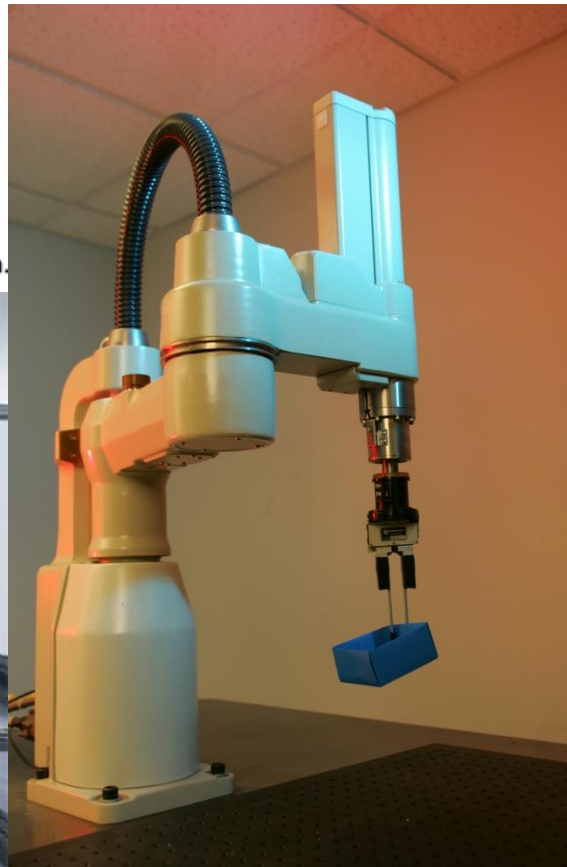


Figure 5. SCARA - Selective Compliance Assembly Robot Arm.



# History of Robotics

- **1980's** – Innovation in improving the performance of robot arms – feedback control to improve accuracy, program compliance, the introduction of personal computers as controllers, and commercialization of robots by a large number of companies: KUKA (Germany), IBM 7535, Adept Robot (USA), Hitachi, Seiko (Japan).
- **Early 1980's** – Multi-fingered hands developed, Utah-MIT arm (16 DOF) developed by Steve Jacobsen, Salisbury's hand (9 dof).
- **1977-1983** – Stanford cart/CMU rover developed by Hans Moravec, later on became the Nomad mobile robot.



# History of Robotics

- **1980's** – Legged and hopping robots (BIPER – Shimoyama) and Raibert 1986.
- **1984 -1991** – V. Braitenberg revived the tortoise mobile robots of W. Grey Walter creating autonomous robots exhibiting behaviors. Hogg, Martin and Resnick at MIT create mobile robots using LEGO blocks (precursor to LEGO Mindstorms). Rodney Brooks at MIT creates first insect robots at MIT AI Lab – birth of behavioral robotics.

# History of Robotics

- **1986** - Honda starts work on its first humanoid, [robot named 'E0'](#) (later to become [ASIMO](#)).
- **1988** - SCAMP designed as the first robot pet with emotions.
- **1989** - Mark Tilden introduces [BEAM robotics](#), beam being an acronym for Biology, Electronics, Aesthetics, and Mechanics.
- **'90**: modifiable robots for assembly. Mobile autonomous robots. Vision controlled robots. Walking robots.
- **1991** - First HelpMate mobile autonomous robot used in hospitals.

# History of Robotics

- 1990's – Humanoid robots – Cog, Kismet (MIT), Wasubot, WHL-I – Japan, Honda P2 (1.82m, 210kg), and P3 (1.6m, 130kg), ASIMO.
- 1990's – Entertainment and Education Robots – SARCOS (“Jurassic Park”), Sony AIBO, LEGO Mindstorms, Khepera, Parallax.
- ROBOCUP, the competition simulating the game of soccer played by two teams of robots having been held around the world since 1997 (Osaka) .

# History of Robotics

- **1997** - [Sojourner](#) becomes the first rover to land on Mars as part of the [Mars Pathfinder mission](#).
- **1998** - Lego enters the robotics market with its first version of Lego Mindstorms.
- **1999** - Sony introduces [AIBO](#), an autonomous robotic dog capable of seeing, walking and interacting with its environment. This was followed a year later by the SDR-3X humanoid robot later known as [QRIO](#) (both discontinued in 2006).

# History of Robotics

- 1990's – Introduction of space robots (manipulators as well as rovers – the MARS rover 1996), parallel manipulators (Stewart-Gough Platforms), multiple manipulators, precision robots (“Robotworld”), surgical robots (“RoboDoc”), first service robots (as couriers in hospitals, etc)

# History of Robotics

- **2000** - Honda unveils [ASIMO](#), the first non-prototype release of its humanoid robot.
- **2001** - US Air force test the [MQ-1 Predator](#), the first armed [unmanned aerial vehicle \(UAV\)](#) fitted with two Hellfire missiles.
- 2000's – IRobot introduces the first autonomous vacuum – “Roomba”.
- 2000's – Mini and micro robots, “Smart Dust” – Pister @ Berkeley, UTA, EPFL/Lausanne, microfactories.

# History of Robotics

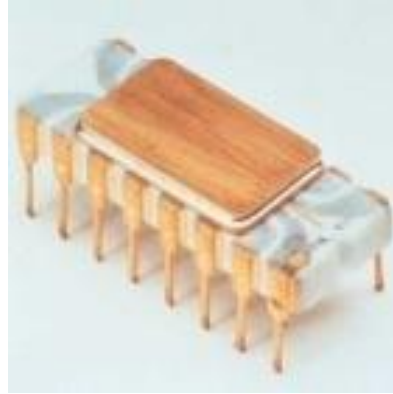
- 2000's – Military applications - Robotic assistants for dangerous environments and reconnaissance, AUV's and UUV's, etc.
- 2000's – Intuitive Surgical introduces the Da Vinci surgical robot.
- 2000's – Robotic Deployment of Sensor Networks



# History of Robotics



Lunokhod 1



Intel 4004



R2-D2 and C-3PO



Asimo



Sojourner



Lego Mindstorms

# History of Robotics



Sony AIBO



Sony QRIO



MQ-1 Predator

# History of Robotics

- **2002** - [iRobot](#) introduces [Roomba](#), a personal robotic vacuum cleaner.
- **2003** - Osaka University unveils their first '[Actroid](#)', the term given for a humanoid robot with strong visual human characteristics.
- **2004** - The first [DARPA Grand challenge](#) is held. Sponsored by the US department of defence, the challenge is designed to create autonomous vehicles for warfare.
- **2004** - The [Mars rovers Spirit and Opportunity](#) land on Mars. As of November 25th 2009 The rover Spirit has completed 2150 days of its 92 day (90 sol) mission.
- **2010** - [NASA](#) and General Motors join forces to develop [Robonaut-2](#), the new version of NASA's humanoid robot astronaut.

# History of Robotics



Actroid



Mars Exploration Rover



Robonaut-2

# History of Robotics

Should robots look like humans?

**“anthropomorphic or humanoid robots”.**

Need for these machines to also be intelligent - link to **“Artificial Intelligence (AI)”**.

Need for humans to create machines similar to them is rooted in religious beliefs, recommended reading **“God in the Machine”** by **Anne Foerst**

It is not the appearance of the robot that most connects it to humans: HAL in “Space Odyssey 2001”, Lt. Data in “Startrek-TNG”, R2D2 and C3PO in “Star Wars”. Which one is more “likeable” and why?



# History of Robotics

Robots need not look like humanoids, but they make use of:

Strong & precise articulated arms to accomplish tasks that were performed by humans – **“articulated robots”, or “manipulators”**.  
**Fear that they will replace human laborers.**

Use of mobility to reposition the robot from one location to another, **“mobile robots”**. **This can be done by locomotion like humans do (“legged robots”), but most likely it will use other means such as wheels (“wheeled robots”).**



# History of Robotics

- Robotics is a multi-disciplinary field. Best robotics researchers and engineers will touch upon all disciplines:
- **Mechanical Engineering** – concerned primarily with manipulator/mobile robot design, kinematics, dynamics, compliance and actuation.
- **Electrical Engineering** – concerned primarily with robot actuation, electronic interfacing to computers and sensors, and control algorithms.
- **Computer Science** – concerned primarily with robot programming, planning, and intelligent behavior.

# So What is a Robot?

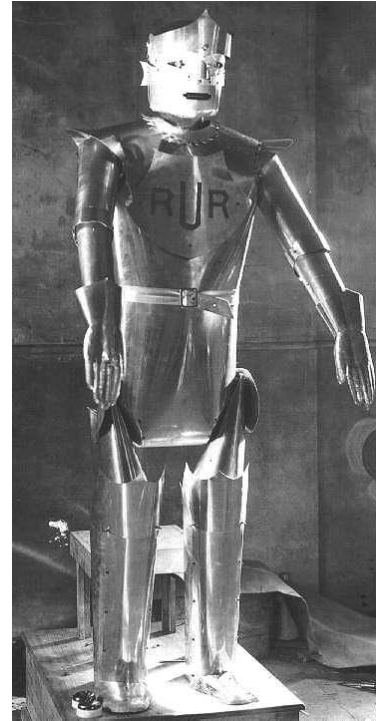
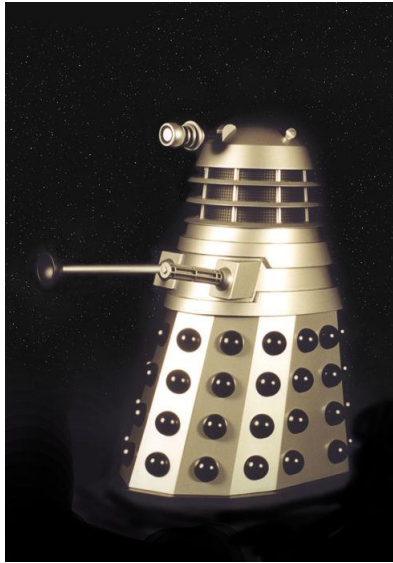


# Robot timeline?



# *Fictional* Robot timeline

Putting these robots in chronological order?

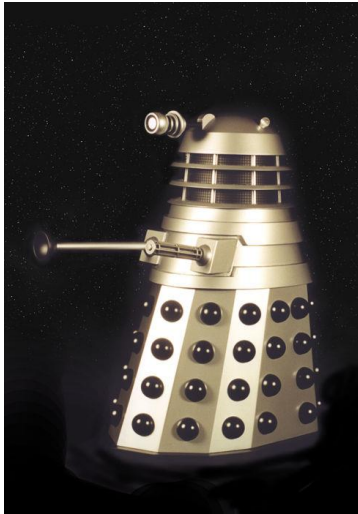
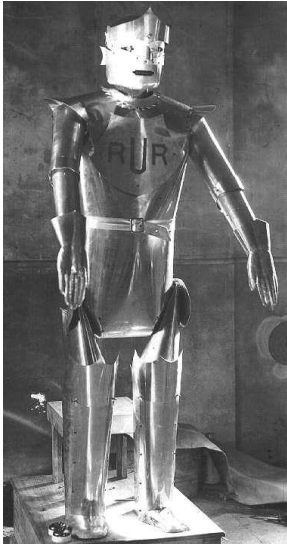


# Fictional robot timeline

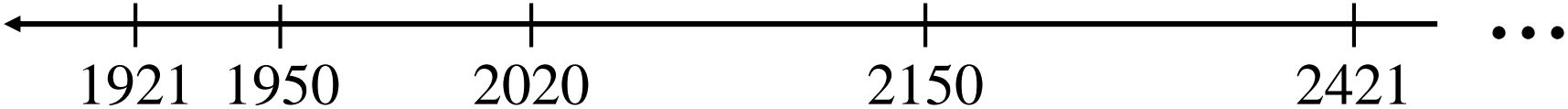


Karl Capek

Rossum's Universal Robots



I, Robot Asimov





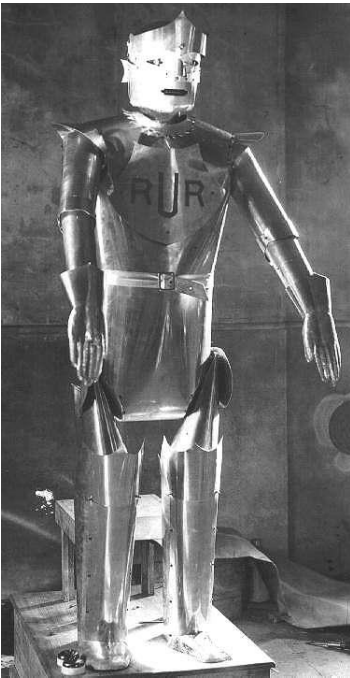
# Robot timeline

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Karl Capek

Rossum's Universal Robots



Isaac Asimov's Laws of Robotics

## First Law:

A robot may not injure a human being, or, through inaction, allow a human being to come to harm.

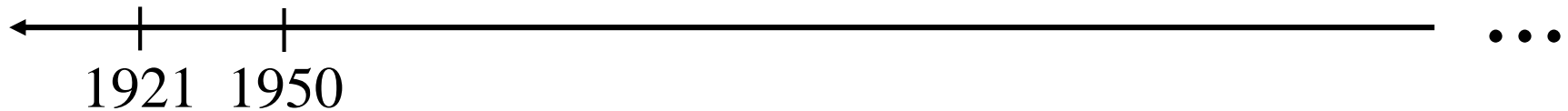
## Second Law:

A robot must obey orders given it by human beings, except where such orders would conflict with the First Law.

## Third Law:

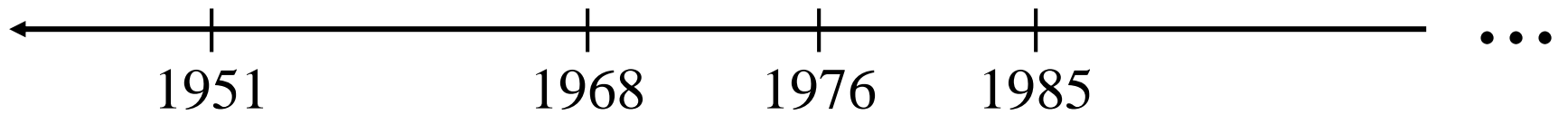
A robot must protect its own existence as long as such protection does not conflict with the First or Second Law.

I, Robot



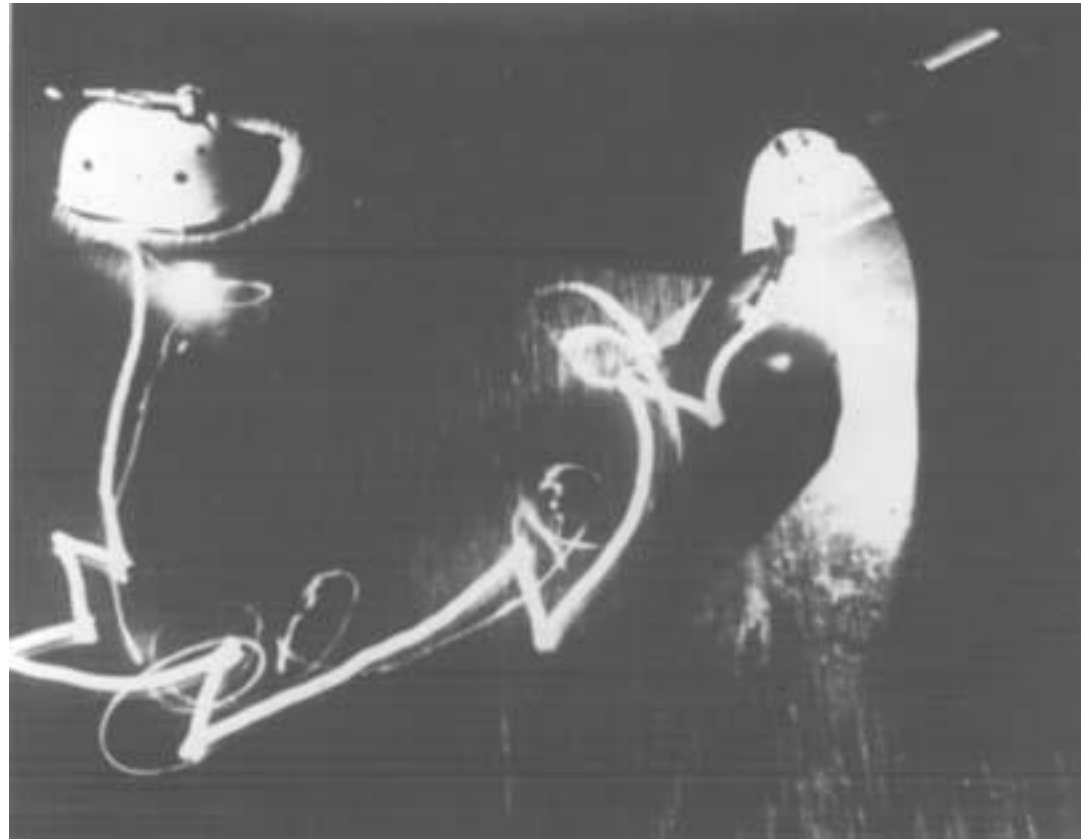
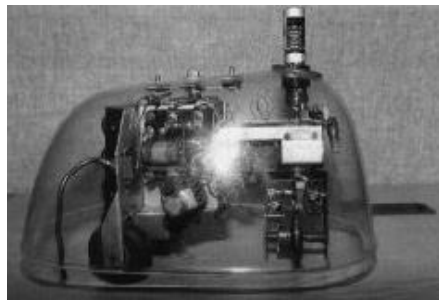
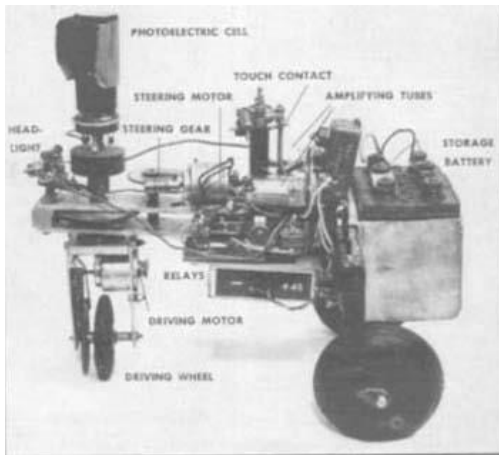


# *Real* robot timeline

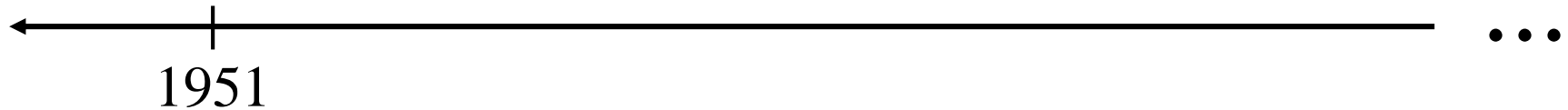


# *Real* robot timeline

## Tortoise “Elsie”



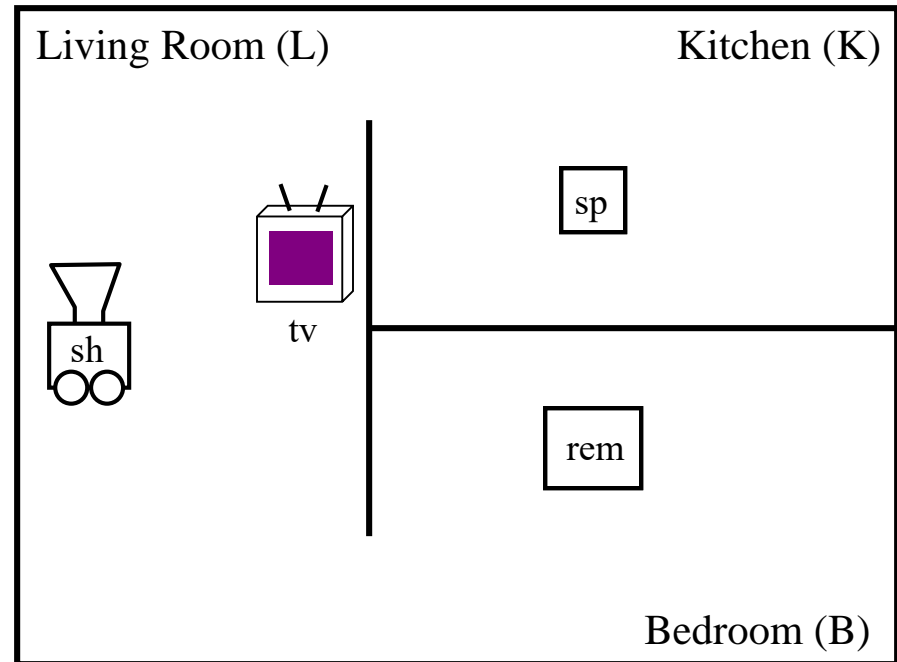
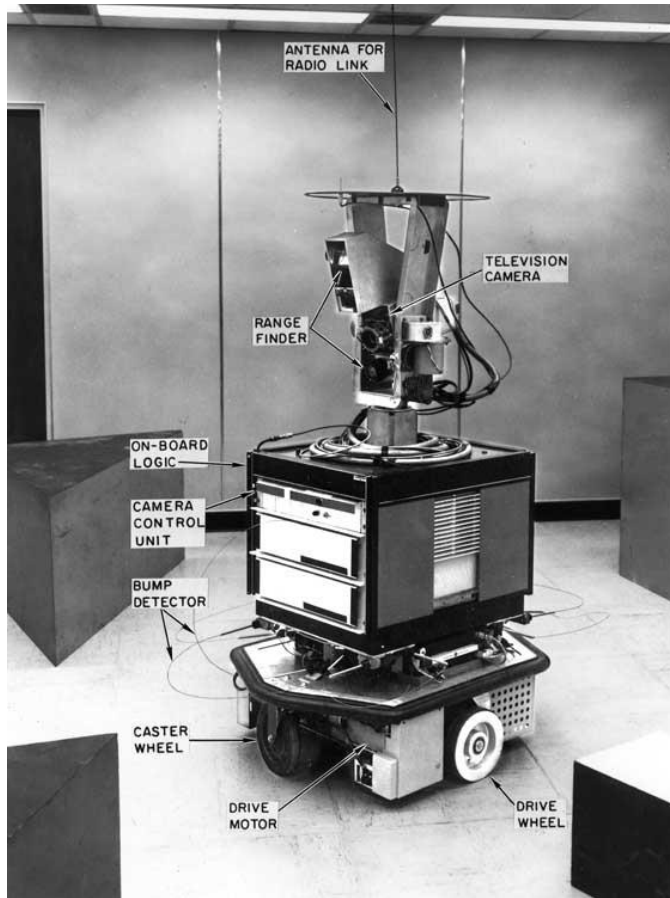
by Neurophysiologist Grey Walter



# Shakey

Nils Nilsson @ Stanford Research Inst.

first “general-purpose” mobile platform

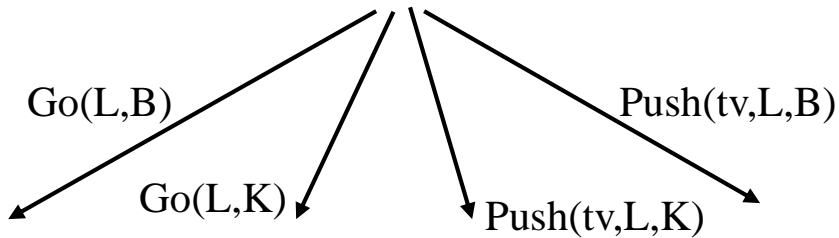


1968

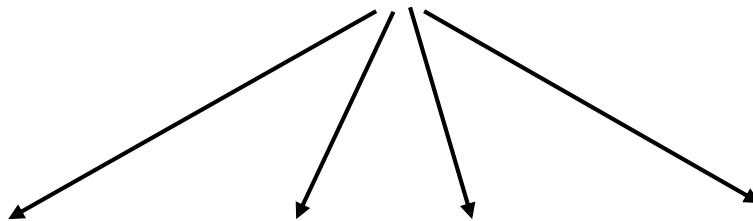
# Robotics's *Shakey* start

START

$At(sh,L) \wedge At(sp,K) \wedge At(rem,B) \wedge At(tv,L)$



$At(sh,K) \wedge At(sp,K) \wedge At(rem,B) \wedge At(tv,K)$



$At(sh,L) \wedge At(sp,L) \wedge At(rem,L) \wedge At(tv,L)$

GOAL

## ACTIONS

- **Go(from,to)**

Preconditions:  $At(sh,from)$

Postconditions:  $At(sh,to)$

- **Push(obj,fr,to)**

Preconditions:  $At(sh,fr) \wedge At(obj,fr)$

Postconditions:  $At(sh,to) \wedge At(obj,to)$

# Stanford Cart: *SPA*

Hans Moravec @ SAIL

“functional” task decomposition →  
“horizontal” subtasks

SENSING

perception

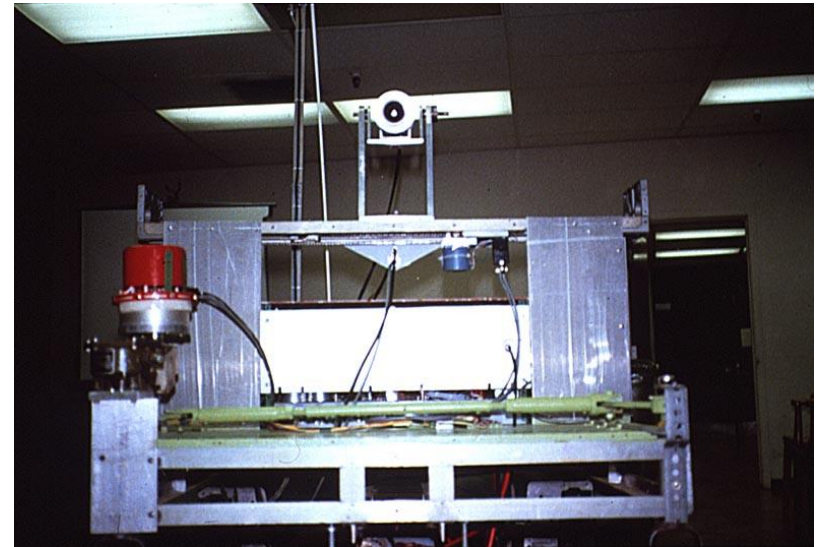
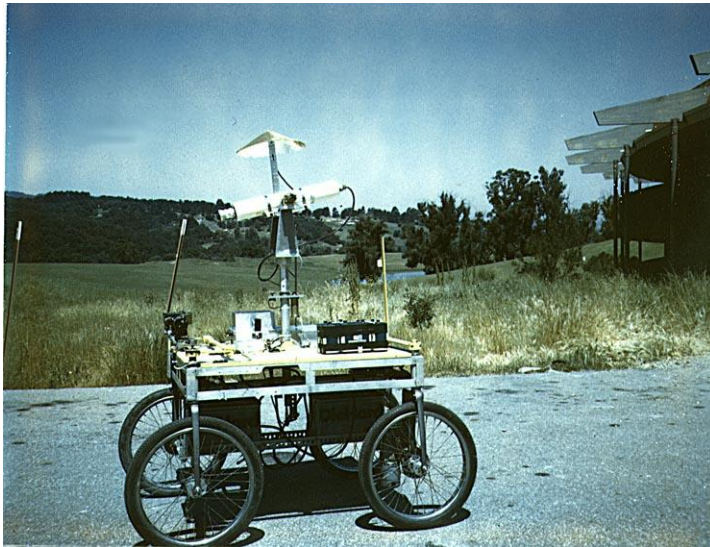
world modeling

Planning

task execution

motor control

ACTING



1976



# Cartland (outdoors)



# Cartland (indoors)

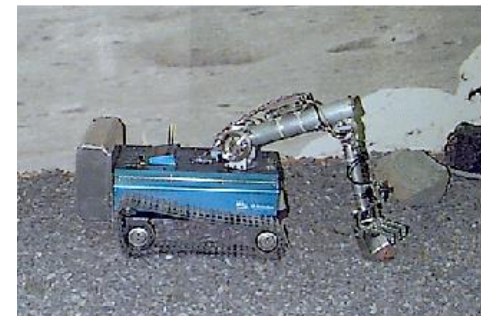
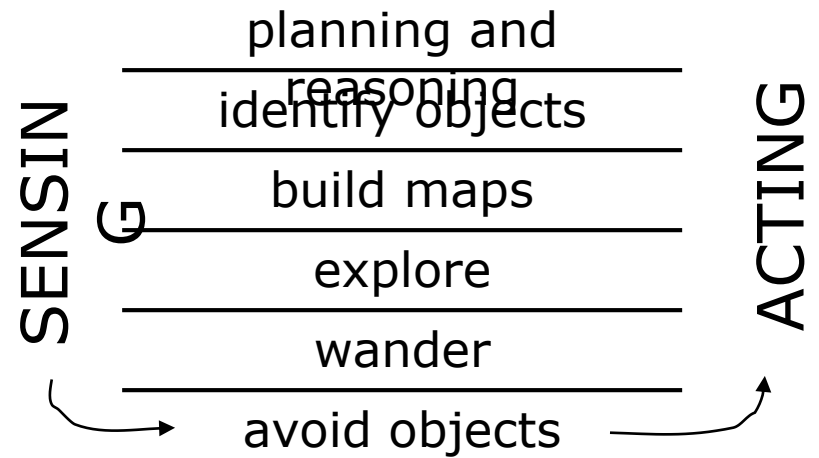




# “Robot Insects”

Rodney Brooks @ MIT

“behavioral” task decomposition →  
“vertical” subtasks



# *Subsumption* Architecture

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**Genghis in action!**



**complex behavior = simple rules + complex environment**

**<http://www.youtube.com/watch?v=BUxFfv9JimU>**

# Robot timeline

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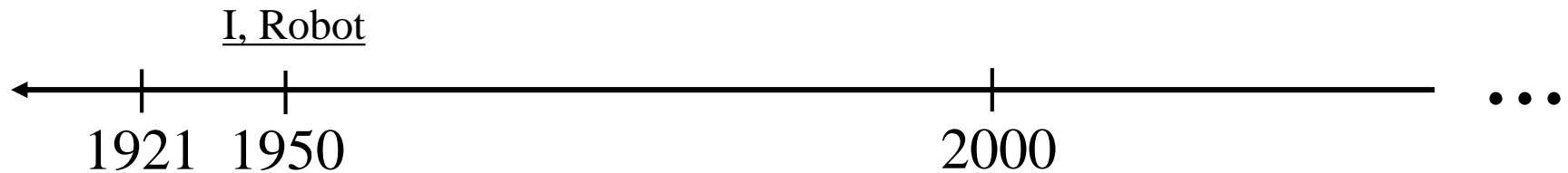
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Robots - a 50 year journey [Video @ ICRA 2000]

<https://vimeo.com/137042620>

The journey continues:

<https://vimeo.com/173394878>



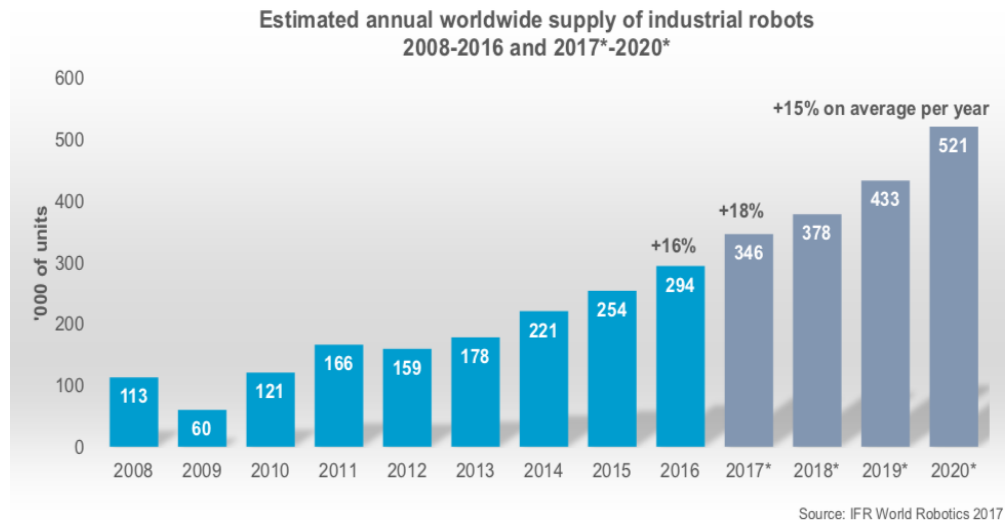
# Robotics (turnover over \$40 billion\*)

Industrial Robotics - Service Robotics

Industrial Robots	Service Robots	
 <p data-bbox="175 1100 537 1133">Industrial environments</p>	<p data-bbox="884 544 1147 576">Professional Use</p> 	<p data-bbox="1425 544 1715 576">Personal/domestic</p> 
<p data-bbox="948 1100 1425 1133">Non-industrial environments</p>		

\*IFA robotics, 2016

# Trends in robotics



## Professional service robots: significant growth

2016: almost 60,000 units, +24%

Forecast 2017: +17% -almost 79,000 units

Forecast 2018 -2020: about 400,000 units  
20% to 25% on average per year

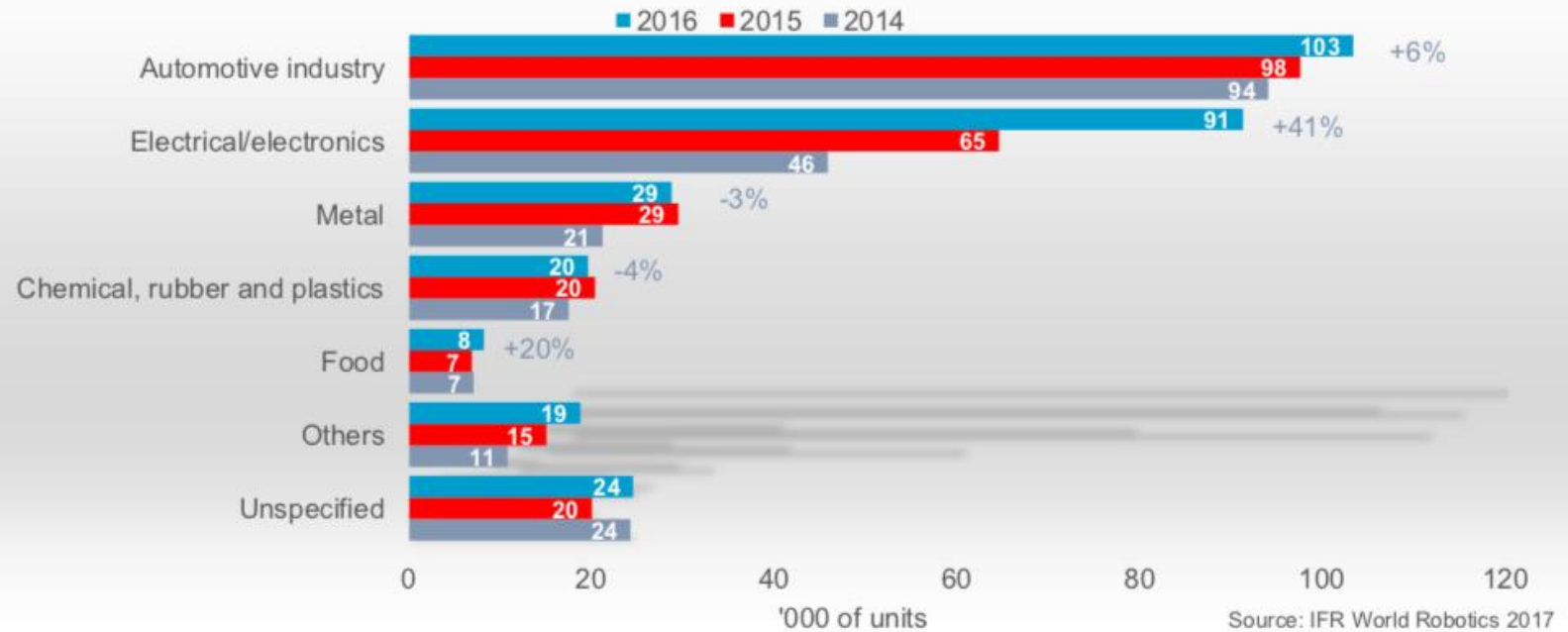
1.7 million new industrial robots by 2020

Double-digit average annual increase

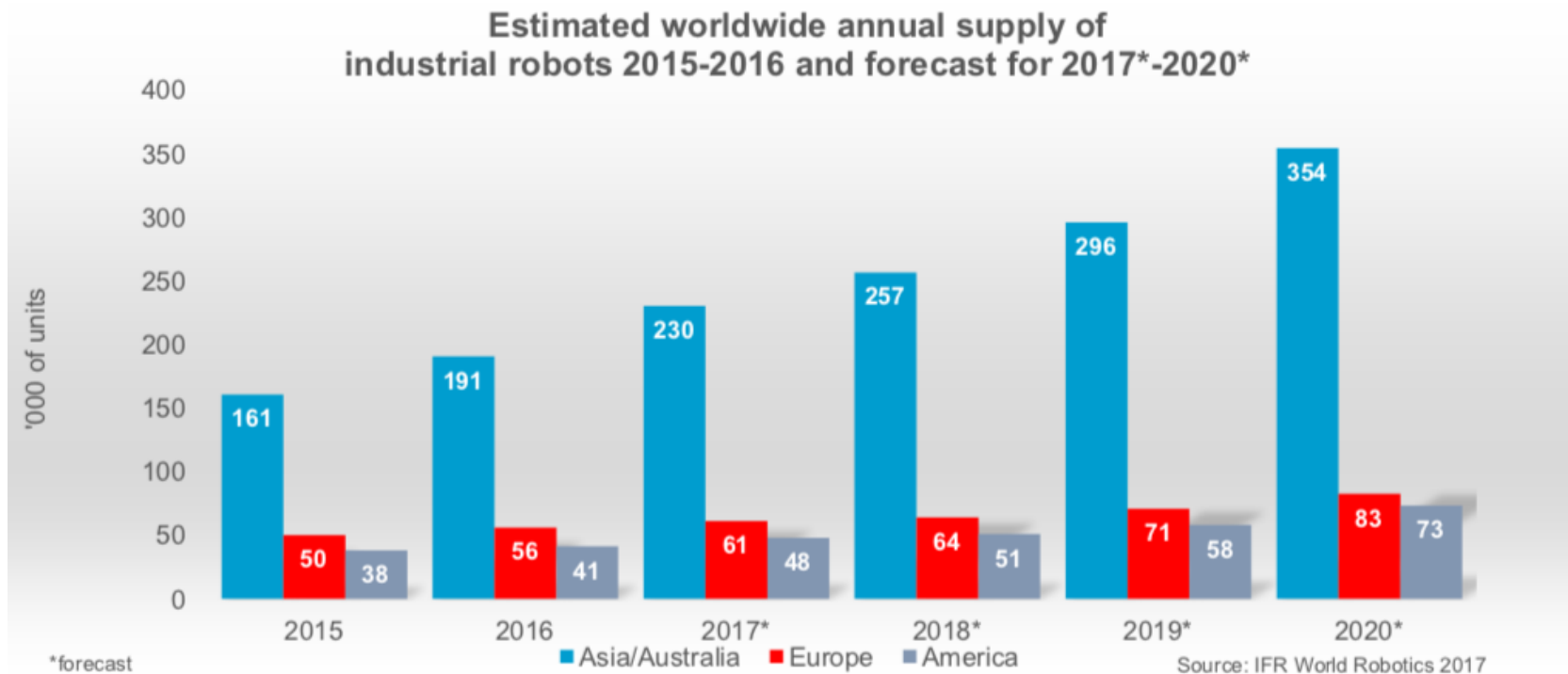
# Trends in robotics

## Continued increase in major industries

Estimated annual supply of industrial robots at year-end  
by industries worldwide 2014-2016



# Trends in industrial robotics





# Trends in service robotics

Fresh fruit picking robot Platform for vineyard maintenance



FF Robotics (Israel)



WALL-YE (France)



Unity Robotics (D)



Mobile Industrial Robots MiR (DK)

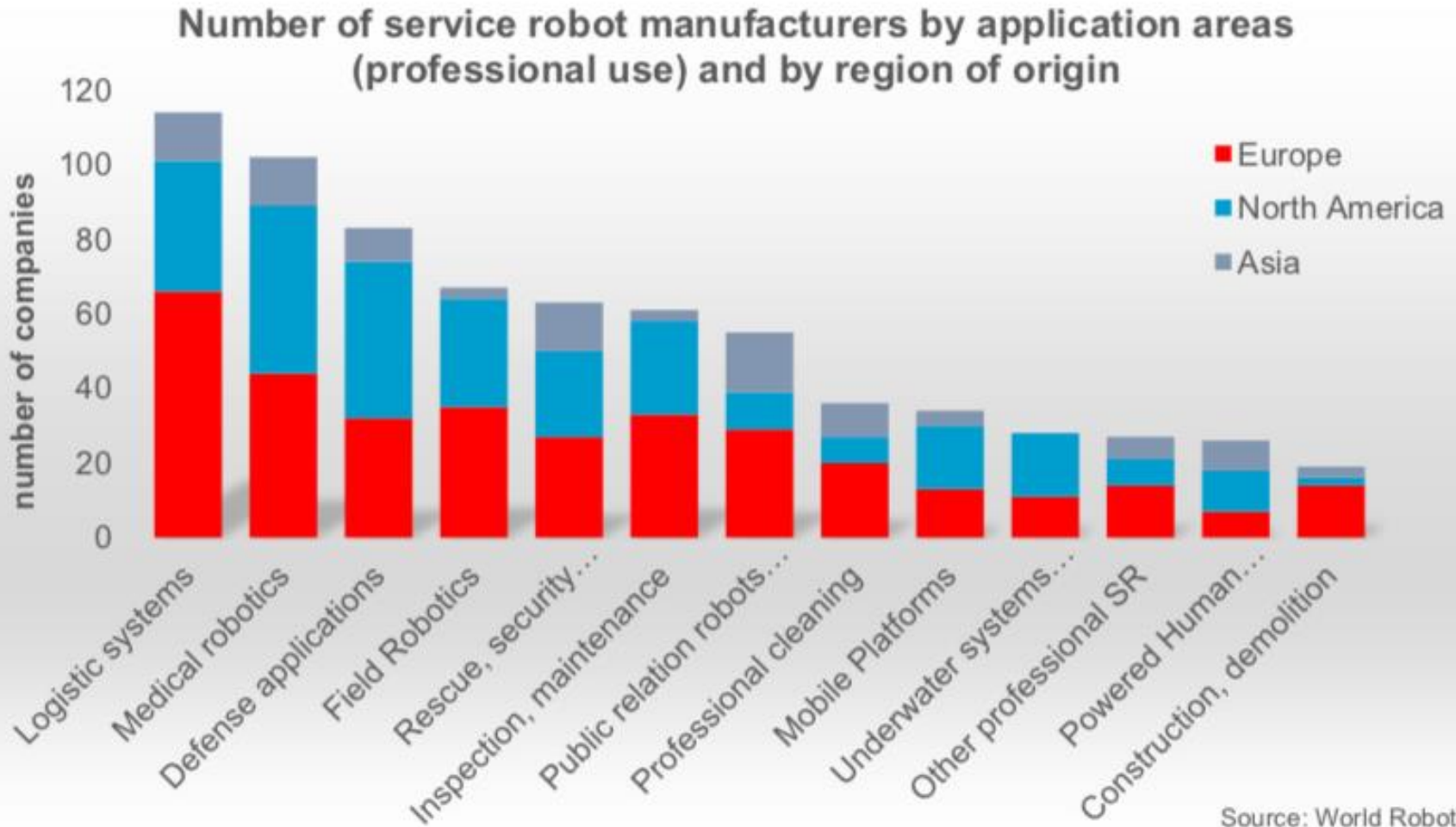


Fetch Robotics (USA)



Robotnik (ES)

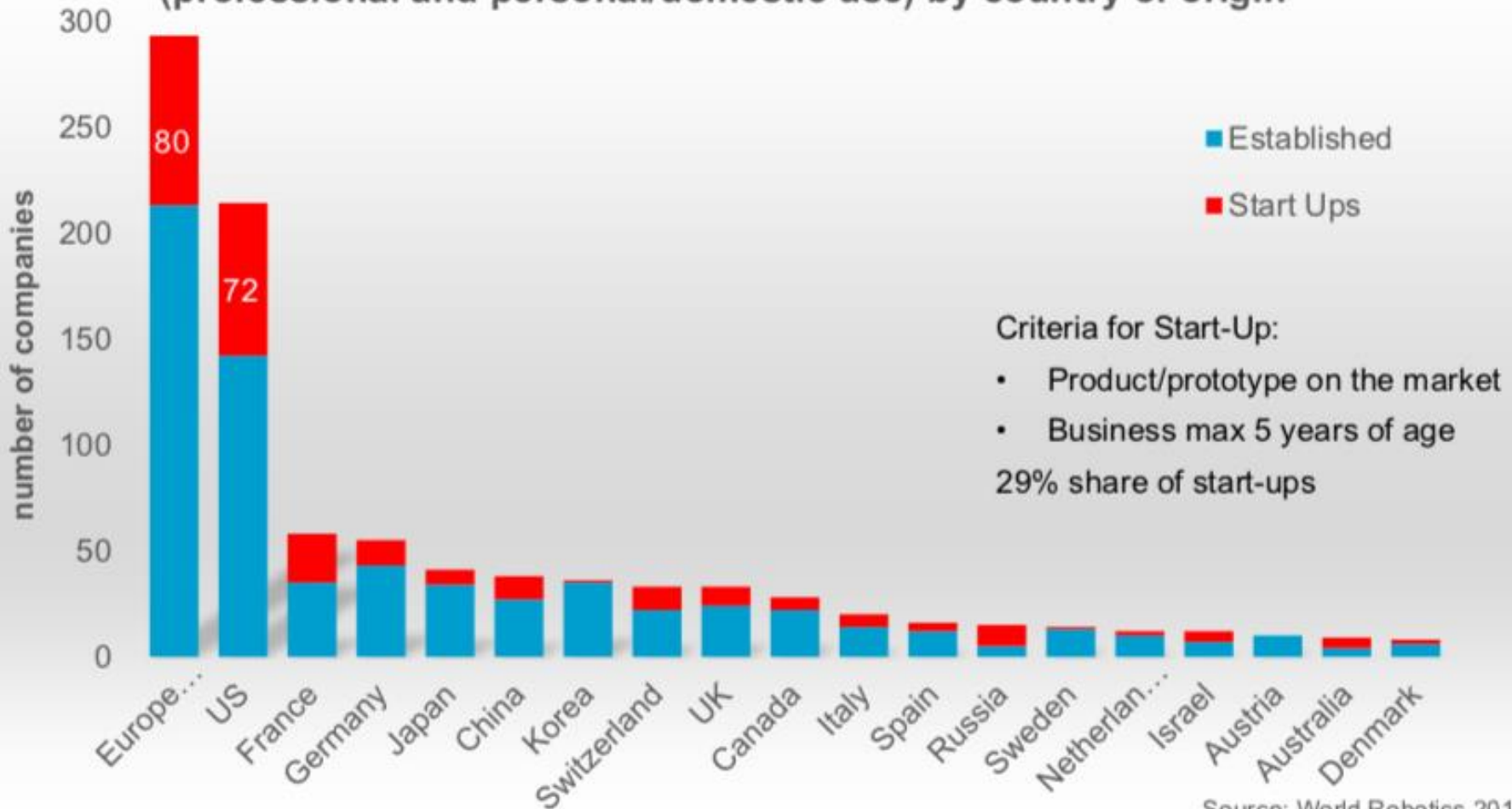
# Trends in service robotics



Source: World Robotics 2017

# Trends in service robotics

Number of service robot manufacturers  
(professional and personal/domestic use) by country of origin



# Canadian Robotic Startups

- **Kinova** robotics (2006): assistive robotic platform
  - \$25M funding Sept., 2017
  - Brain-controlled robot arm  
[https://www.youtube.com/watch?time\\_continue=52&v=-Vh0IJRbOsY](https://www.youtube.com/watch?time_continue=52&v=-Vh0IJRbOsY)
- **RobotiQ** (2008): Adaptive Grippers (Laval Uni.)
- **Clearpath** Robotics (2009): self-driving mobile robots (U-waterloo)
  - from 365K VC founding ... \$30 million in a Series B (2016)
- **SkyX** (2015): Drone for monitoring pipelines in oil and gas sector (Ontario)
- **Kindred.ai** (2014): AI grasping technology based on techniques in deep learning and reinforcement learning
  - (\$28 million)

## Watch videos:

- KUKA, spot welding: [http://www.youtube.com/watch?v=1-J\\_EzKm\\_70](http://www.youtube.com/watch?v=1-J_EzKm_70)
- KUKA dance: <http://www.youtube.com/watch?v=OW4cYdsUpAw&feature=related>
- Industrial robotics: <http://www.youtube.com/watch?v=KBLEPlznHWY&feature=related>
- Arc welding robot: <http://www.youtube.com/watch?v=5HphVrleXIQ&feature=related>

ASIMO:

- <http://www.youtube.com/watch?v=5HphVrleXIQ&feature=related>
- <http://www.youtube.com/watch?v=M4rgaLW163k&feature=related>

CyberDog:

[http://www.youtube.com/watch?v=B0qYob\\_vSgo&feature=related](http://www.youtube.com/watch?v=B0qYob_vSgo&feature=related)

Robot-Araigne:

<http://www.youtube.com/watch?feature=endscreen&v=Mfjn79oiM0Q&NR=1>

Hexapod Robot:

<http://www.youtube.com/watch?v=-uKIDyFMtyQ&feature=related>

- **Hexapod Project:**

[http://www.youtube.com/watch?v=65L\\_FO8cBgA&feature=related](http://www.youtube.com/watch?v=65L_FO8cBgA&feature=related)

- MTRAN Modular Robot:

<http://www.youtube.com/watch?v=4oSavAHf0dg&feature=related>

Also watch:

<http://www.youtube.com/watch?v=nkqesLSXe4Q&feature=related>

<http://www.youtube.com/watch?v=ilbT2QcPGv0&feature=relmfu>