MTRN 3060: ROBOTICS and AUTOMATIONS

Week 1: Introduction to course, Spatial Descriptions

27 July 2023

MACQUARIE University

Course Introduction

Workshop/Lecture

- Workshop/Lecture Thursday 1 PM-3 PM (14 Sir Christopher Ondaatje Ave - 163 Active Learning Space)

- **Lectures will consist of slide presentations and some times code demonstrations.**

- **Group activities: Students will be required to complete a mix of participation exercises, homework assignments, exam, and practical projects.**

Practicals

- Practicals: Fridays, 13 Research Park Dr - 109 Lab
- Group Activities: Group of 5, please do not change your group
- Five students should move from first class to other classes
- Do not forget the logbook

Assessment:

Final exam for lecture/workshop sessions: 40%. There is no hurdle requirement for the final exam.

In-class activities: 10%. There will be in-class activities that form 10% of your final mark. Therefore, it is important to attend the workshop/lectures.

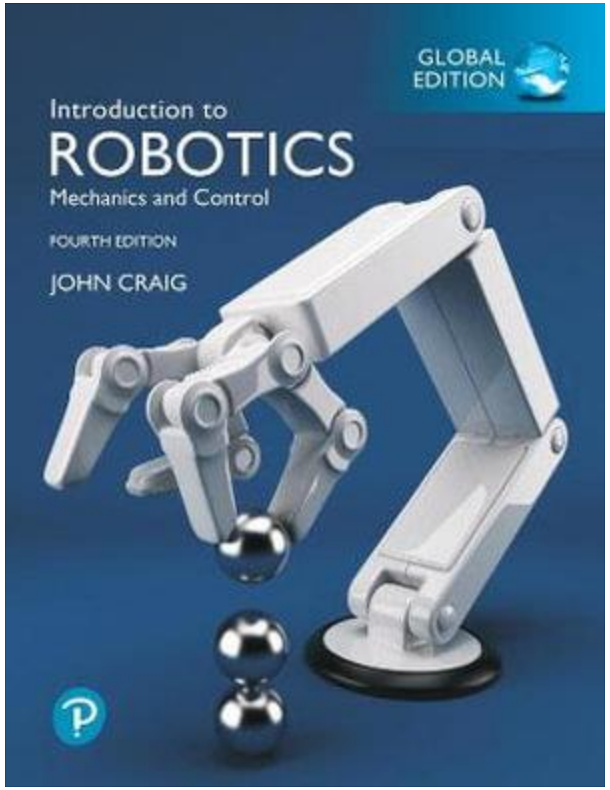
Practical activities: Minor project (Week 5, 10%); Major project (Week 13, 40%).

Course Requirements

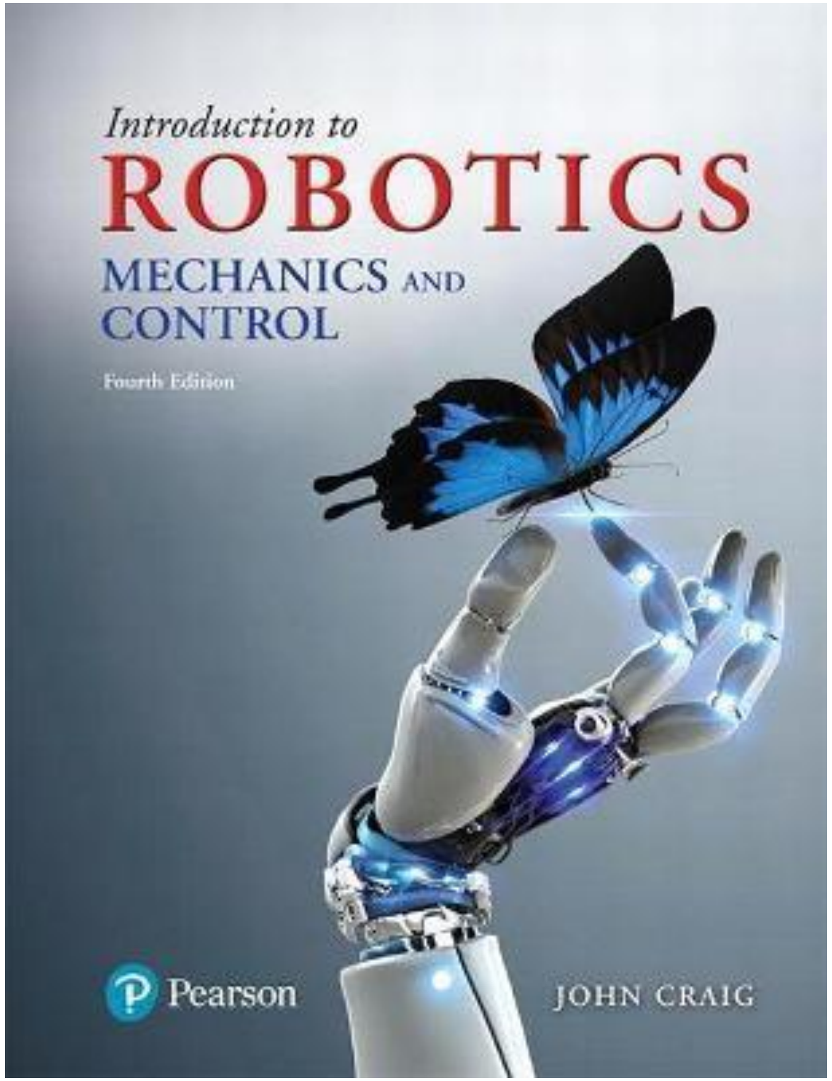
- Textbook: “Introduction to Robotics, Mechanics and Control”, Fourth Edition by John J. Craig, Pearson, 2018,

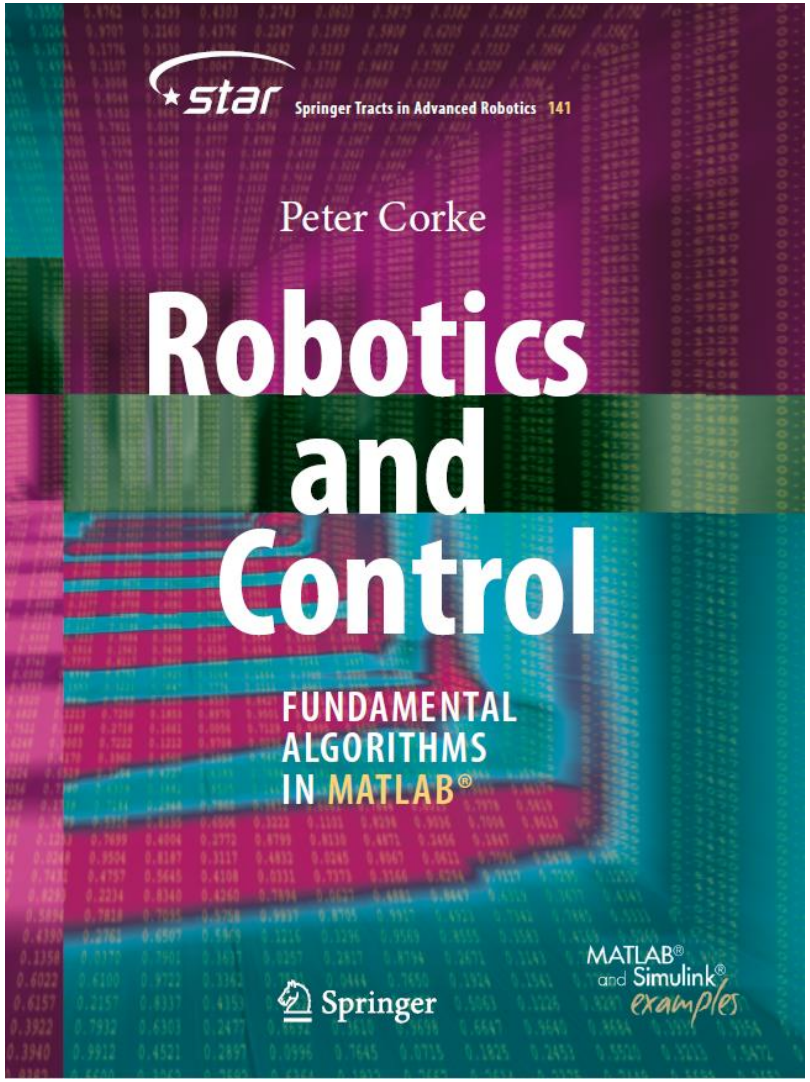
- Programming: MATLAB and Robotic toolbox (by Peter Croke).

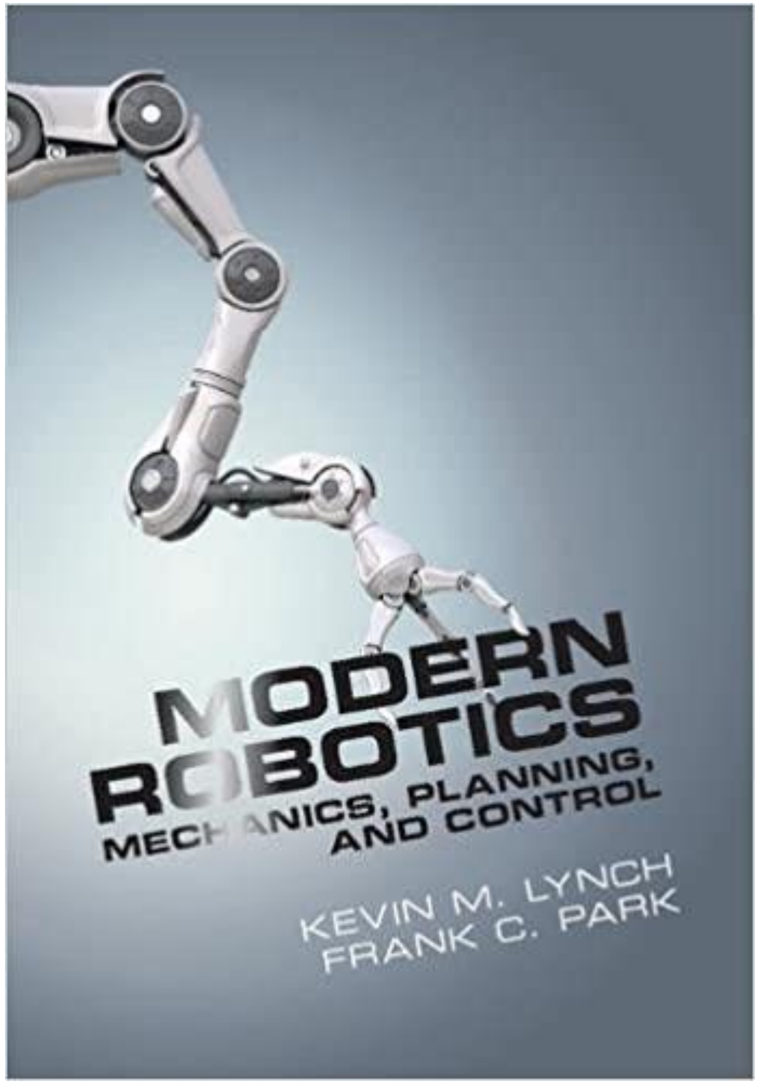
- Background needed: Basic of math, statics and Dynamic, linear algebra and programming



Course Materials







Other helpful materials

MACQUARIE University

- https://robotacademy.net.au/
- https://ocw.mit.edu/courses/mechanical-engineering/2-12-introduction-to-robotics-fall-2005/lecture-notes/
- https://see.stanford.edu/course/cs223a
- https://executive-ed.xpro.mit.edu/robotics-essentials

Week1: Student Learning Outcome

Workshop:

- What is Robotic, Automation
- Catalysers of Innovations in Automation
- Considerations When Automating a Firm

Lecture:

- Description of position and orientation
- Basic Matrix Operations

Practical Session:

- Introduction to safety
- What is robotic
- Simple hands-on example

What is Robotic:

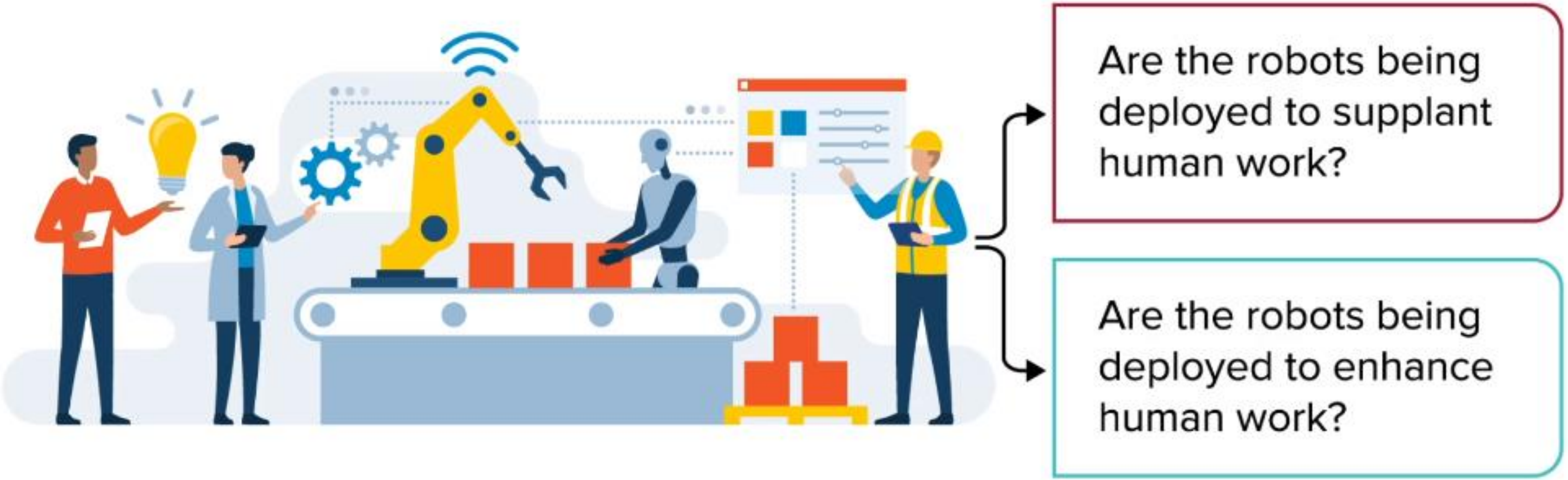
Robotics is an interdisciplinary branch of computer science and engineering, which involves design, construction, operation, and use of robots. The goal of robotics is to design machines that can help and assist humans. Robotics integrates fields of mechanical engineering, electrical engineering, information engineering, mechatronics, electronics, bioengineering, computer engineering, control engineering, software engineering, mathematics, etc.

What is Automation:

Automation describes a wide range of technologies that reduce human intervention in processes. Human intervention is reduced by predetermining decision criteria, subprocess relationships, and related actions — and embodying those predeterminations in machines.

www.Wikipedia.com

A Robot is:



An electromechanical device that is:

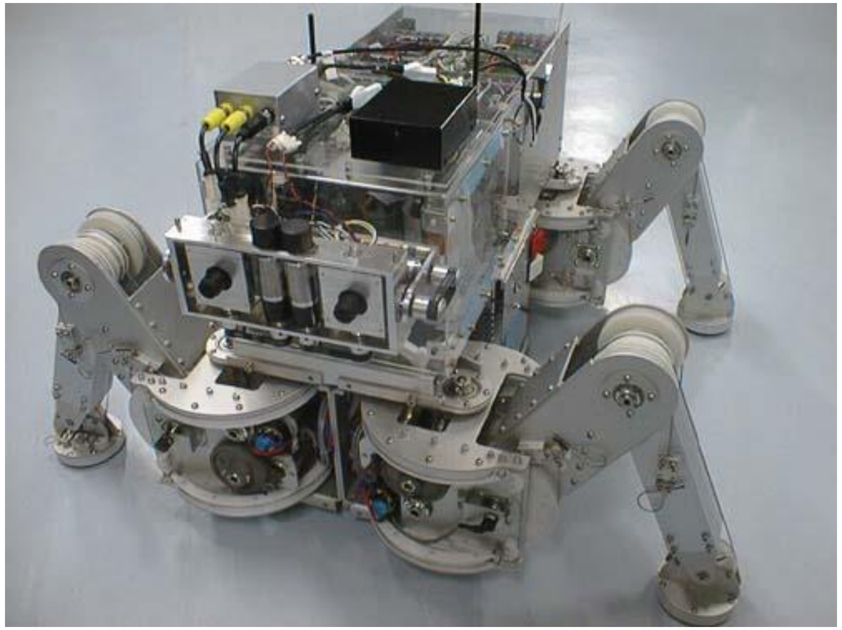
- Reprogrammable
- Multifunctional
- Sensible for environment

What is a Robot:

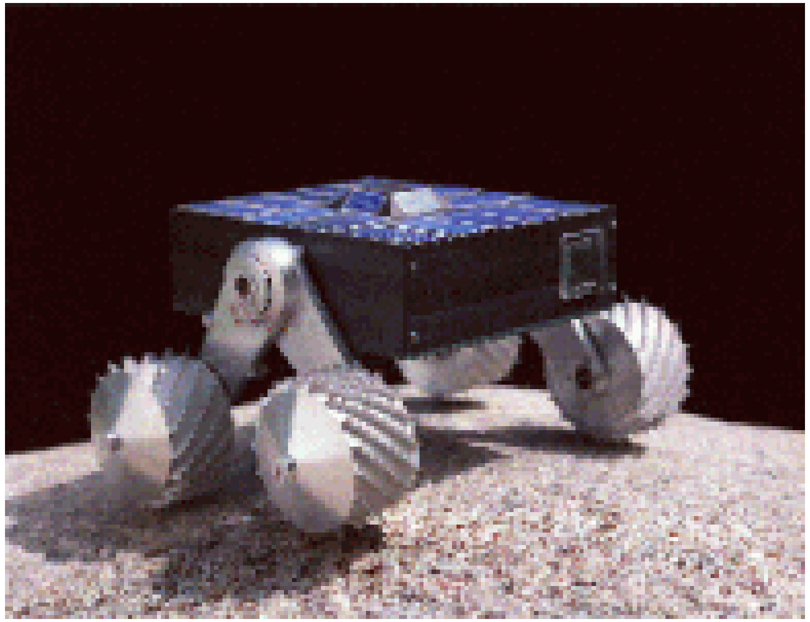
Manipulator

What is a Robot: II

Legged Robot



Wheeled Robot



What is a Robot: III

Autonomous Underwater Vehicle

Unmanned Aerial Vehicle

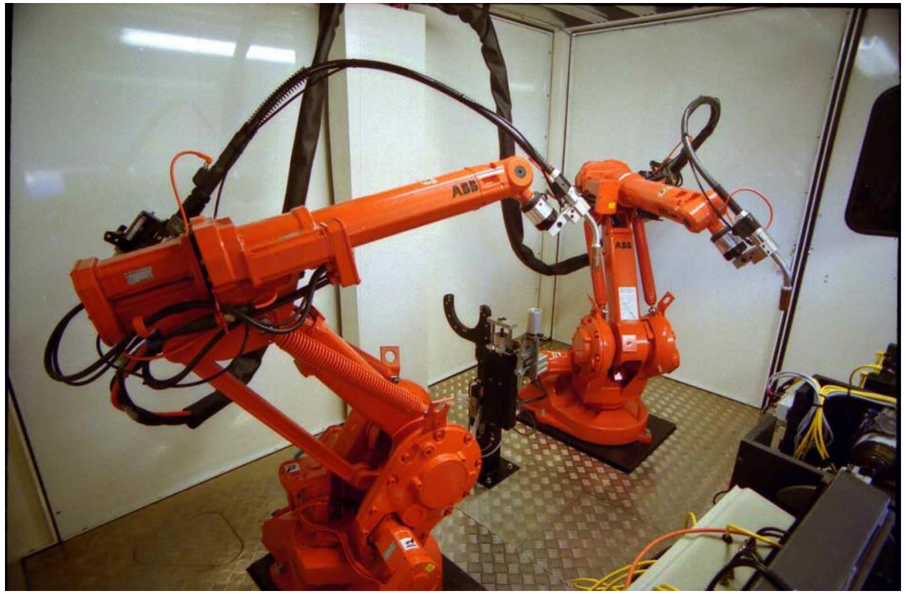
What Can Robots Do: I

Decontaminating Robot

Cleaning the main circulating pump housing in the nuclear power plant

Jobs that are dangerous for humans

What Can Robots Do: II



Welding Robot

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

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**

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. Whereabouts of the duck are unknown today.

1805 - Doll, made by Maillardet, that wrote in either French or English and could draw landscapes.

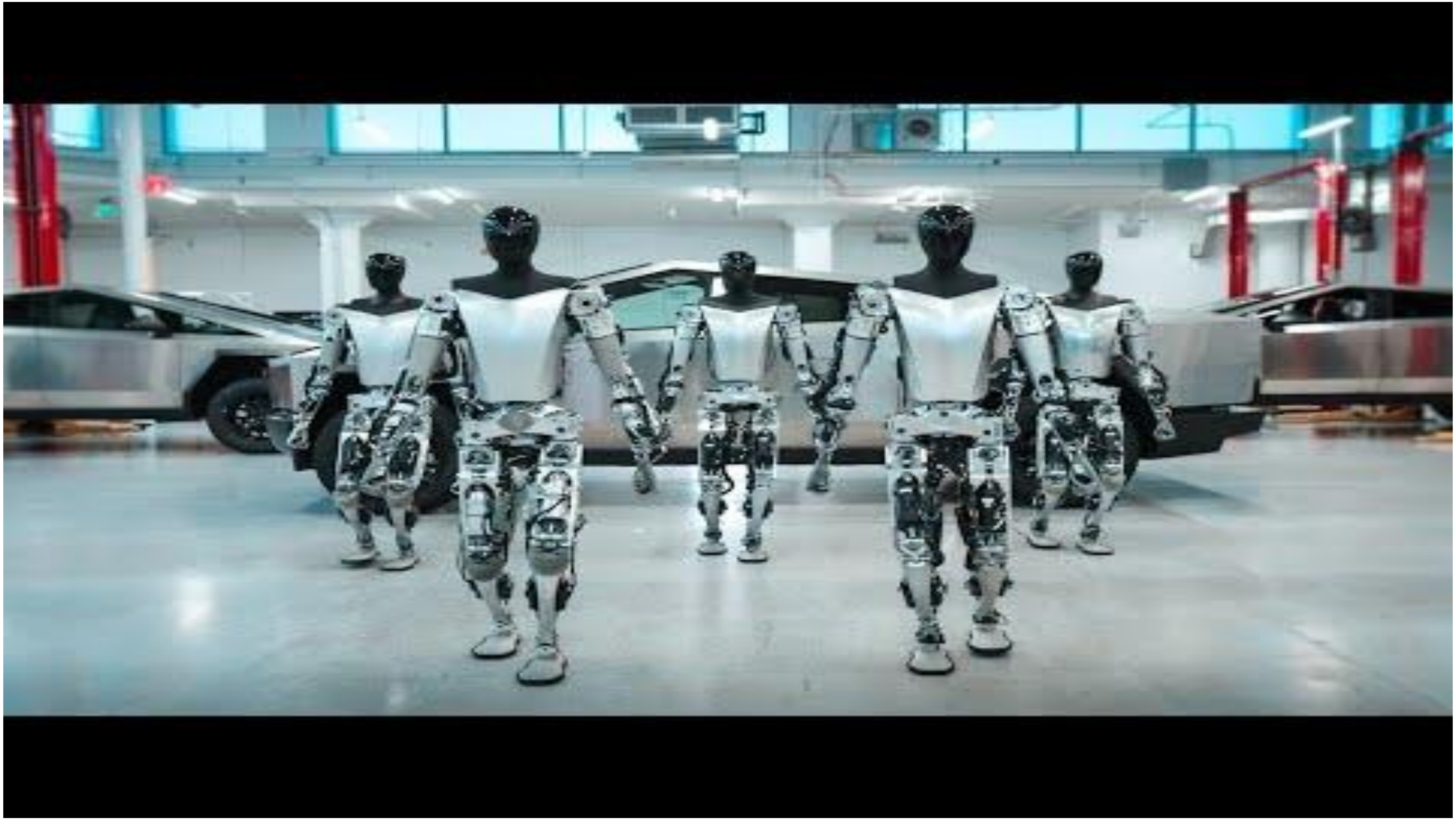
History of Robotics - The Origins of Robots

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”.**



https://www.youtube.com/watch?v=XiQkeWOFwmk&ab_channel=Tesla

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.

Recent Robots (watch in your time)

- Industrial robotics: http://www.youtube.com/watch?v=KBLEPlznHWY&feature=related
- Arc welding robot: http://www.youtube.com/watch?v=5HphVrleXlQ&feature=related

Recent Robots (watch in your time)

ASIMO:

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

Catalyzers of Innovations in Automation

Catalyzers of Innovations in Automation

Necessary technological advances in scalable multi-agent motion planning

Understanding what is easy vs. what is hard to automate

Rethinking the structure of warehouses or distribution centers

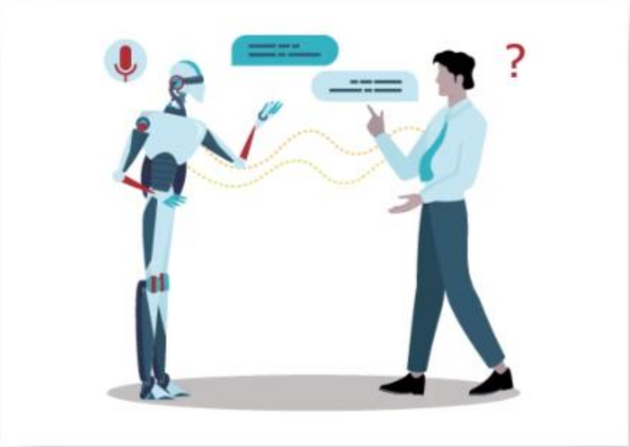
Business outcome of Employing Robots in an Automotive Plant

- Translates to over $80,000 per minute
- Translates to $1 million per three-day shift and $30 million per month
- Reduces the human and robot idle time by 40–80%
- Decreases the time it takes to perform tasks by 5–15%

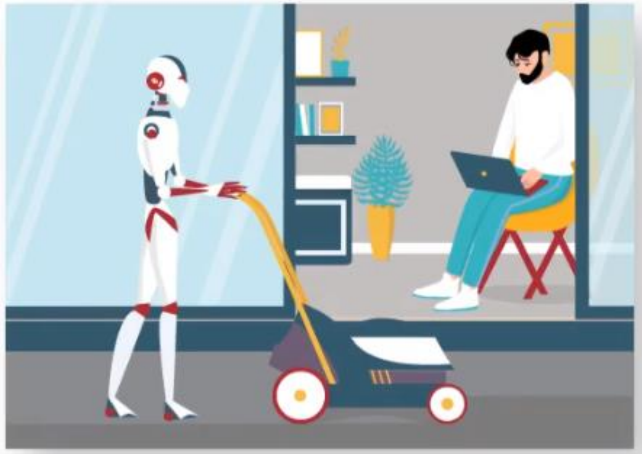
Group Discussion 1

Will be presented and discussed in class

Requirements for Coexistence of Humans and Robots



More transparent communication mechanisms



Safer for humans to work near robots

Better awareness of each other's intentions

What is easy for robot and human

Chess

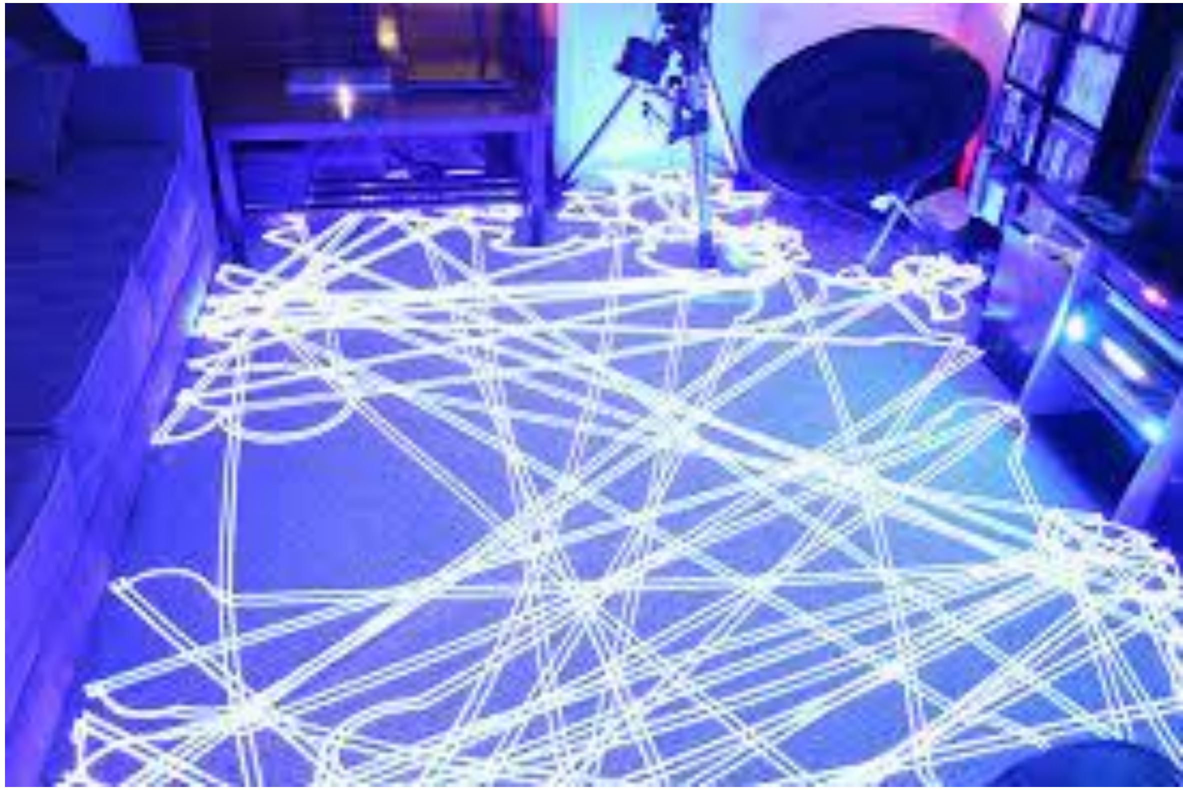
Jenga

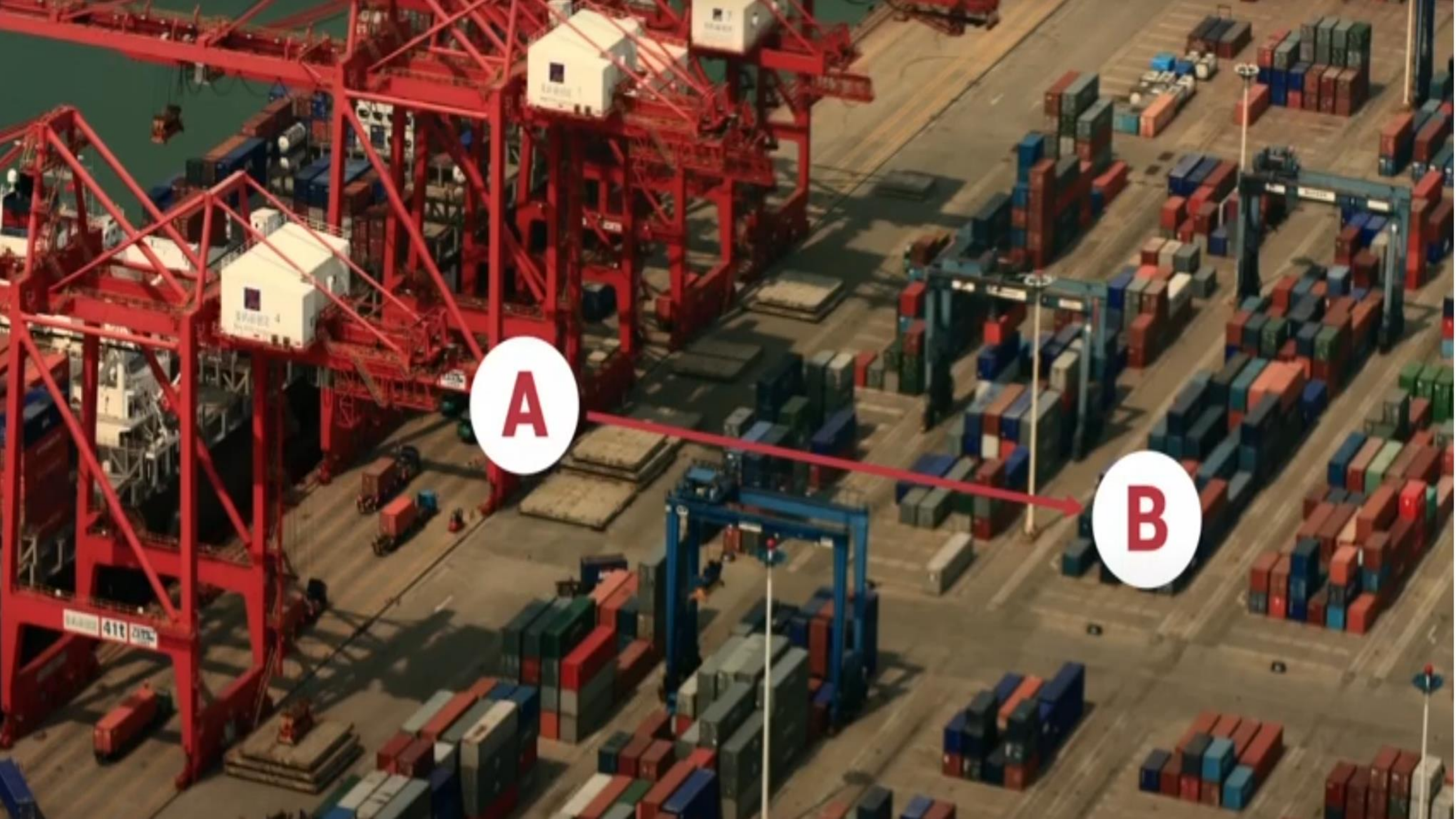
MIT Robot Learns How to Play Jenga

https://www.youtube.com/watch?v=o1j_amoldMs&ab_channel=MITMechanicalEngineering

MORE THAN 1 M in OPERATION

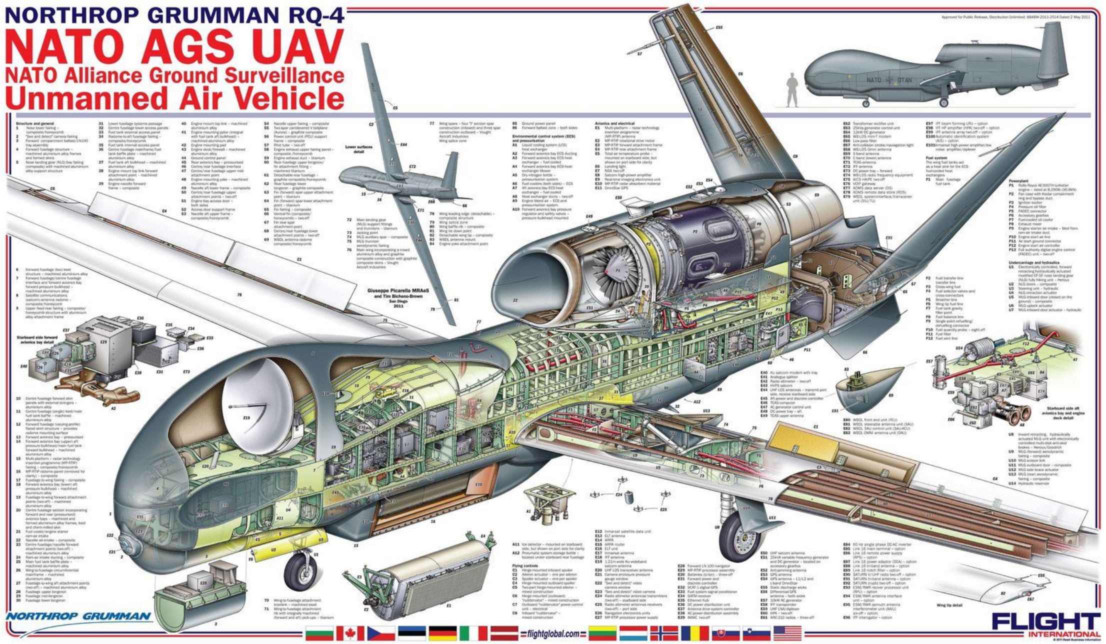
MORE THAN 10 M in OPERATION

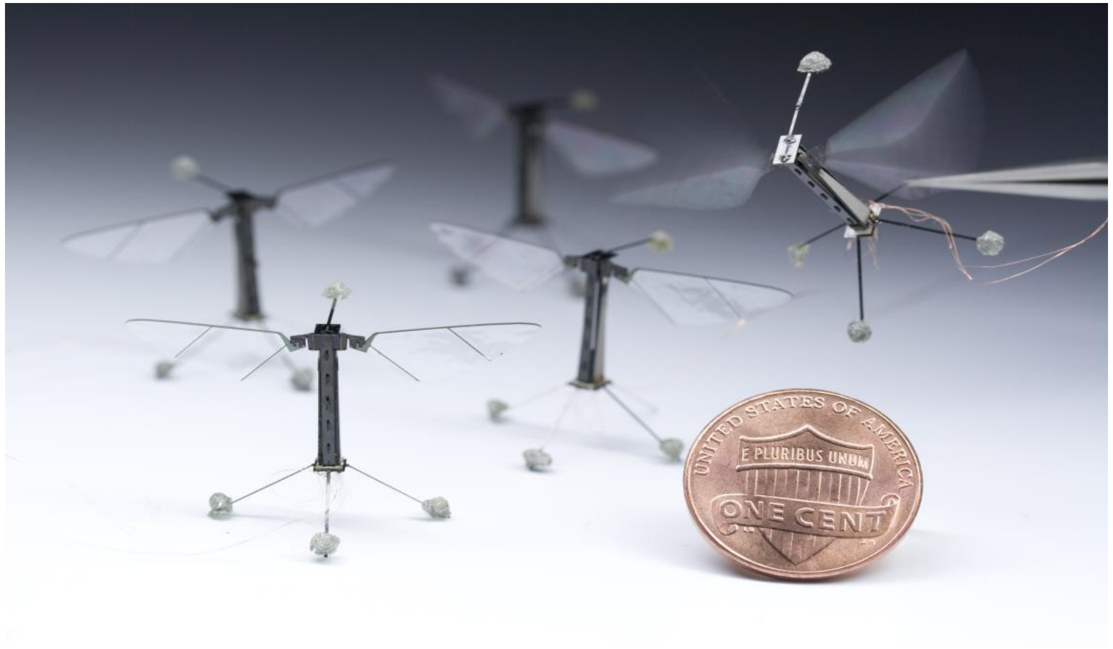



A
B

Robots can Walk

Boston Dynamics


NORTHROP GRUMMAN RQ-4
NATO AGS UAV
NATO Alliance Ground Surveillance
Unmanned Air Vehicle
NORTHROP GRUMMAN
flightglobal.com
FLIGHT
INTERNATIONAL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ONE CENT

Definitions of robot

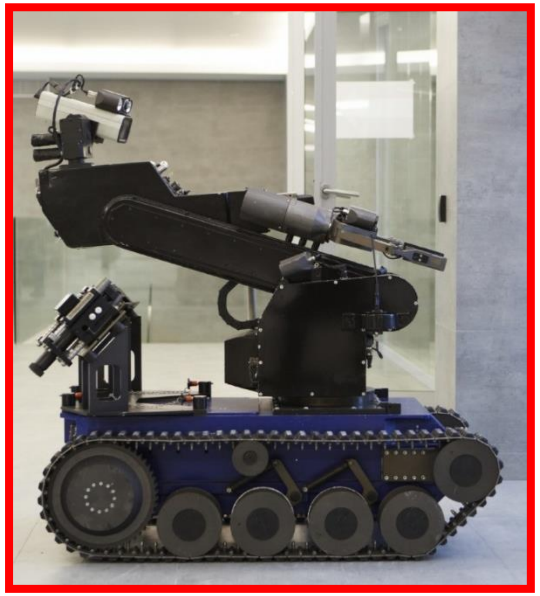

A machine that moves things from A to B

A machine that moves from A to B

A goal oriented machine that can sense, plan and act

Some Applications of Robots

Manufacturing and production line
This robot is moving delicate boxes between conveyor belts in a production line.



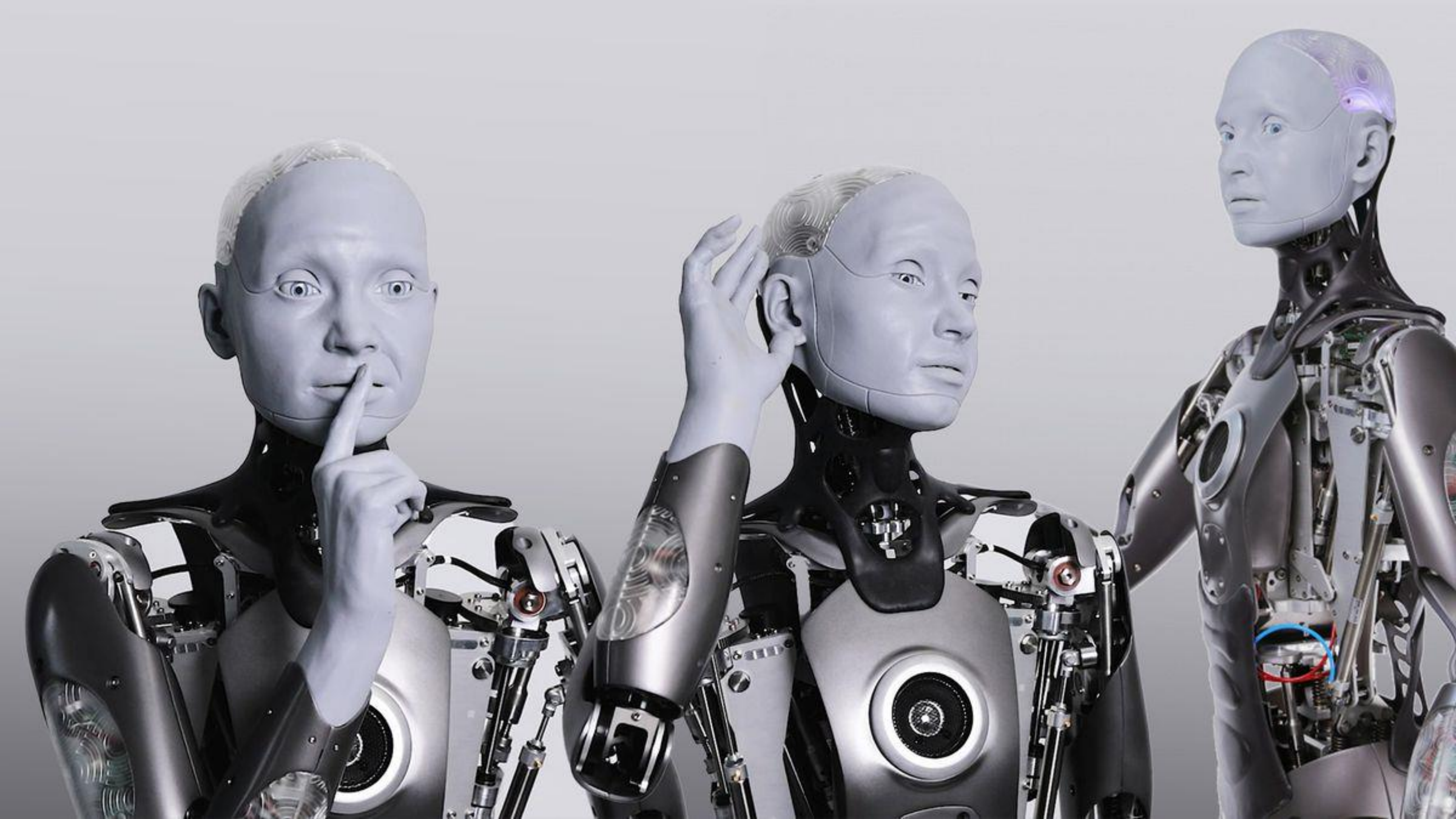
Police response
This robot is conducting dangerous police work

Medical and chemical work
This robot could be organising medical samples or handling dangerous chemicals on behalf of a human

Human like Robots

Requirements:

- Reliable
- Affordable
- Functionality close to that of human being



Robotic Surgery

Application of Robots

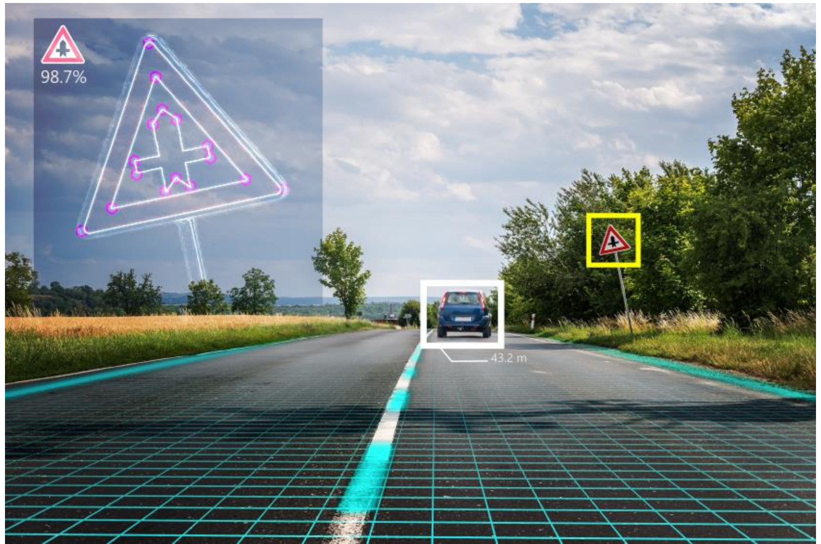
- https://www.youtube.com/watch?v=QksAVT0YMEo

Exoskeleton

Exoskeleton

- https://www.youtube.com/watch?v=lWmFEoDjUc4

Asset Management

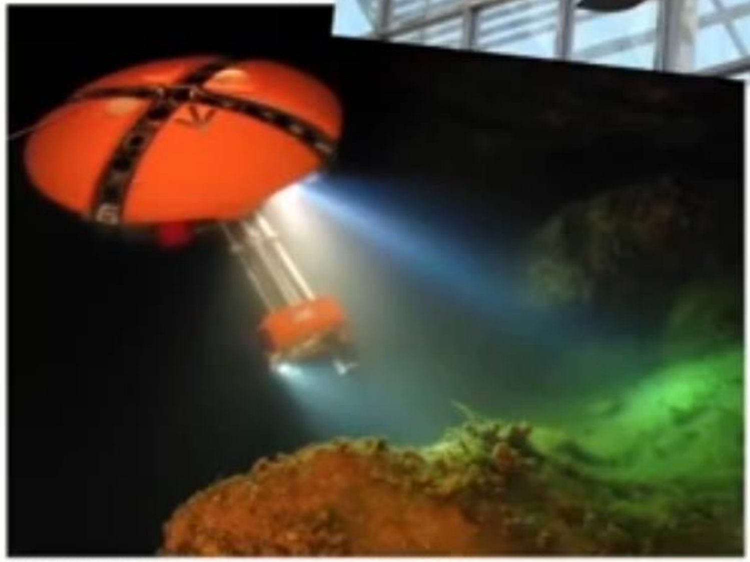


Robots can **explore**

Image: Greg Goebel, 2009

Image: NASA (Bill Ingalls, n.d.).

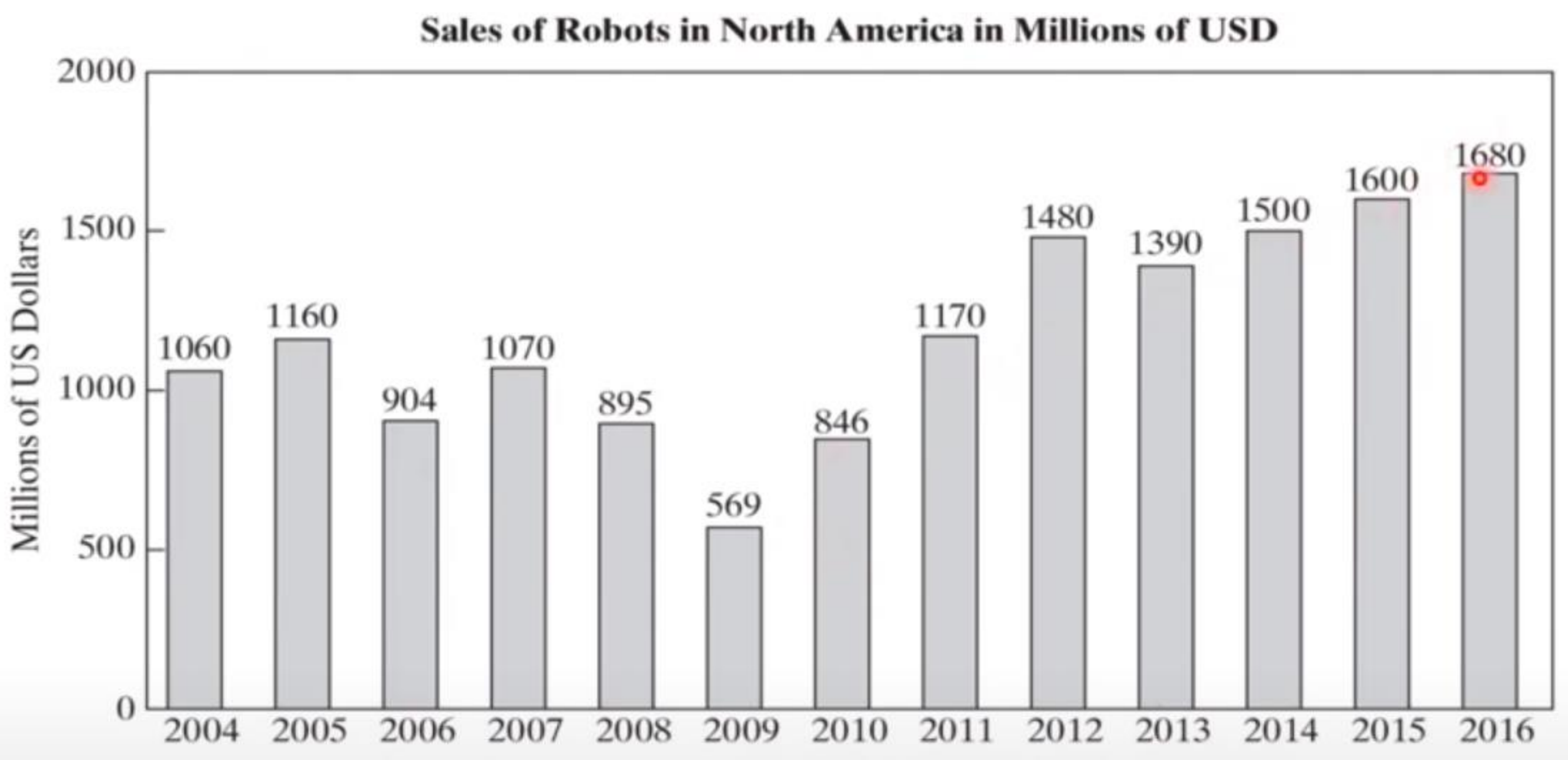
EnviroBlimp test flight in Pittburgh, USA (2001). Image courtesy Carnegie Mellon University.



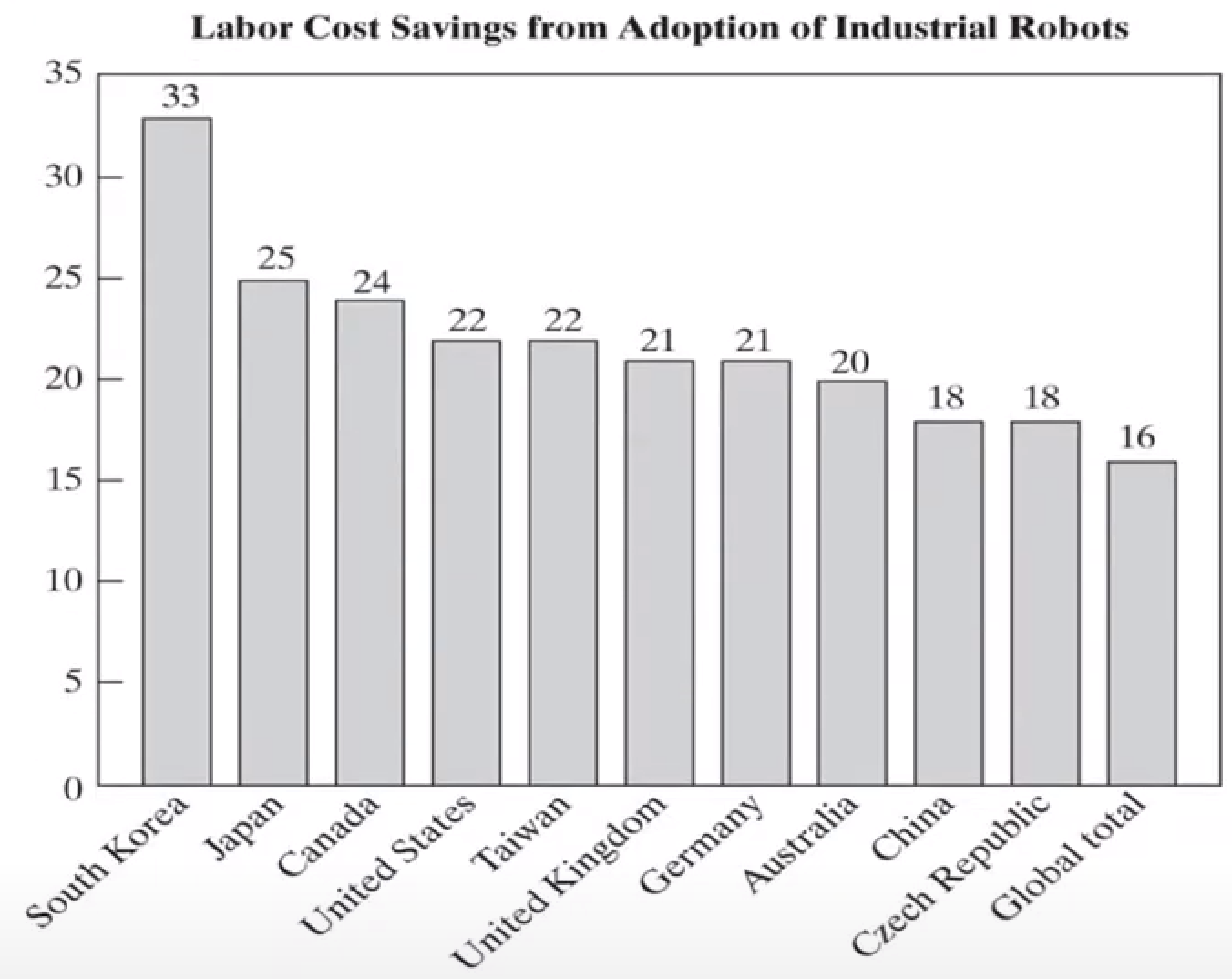
DEPTHX AUV in La Pilita cenote, Mexico (David Wettergreen, 2007). Image courtesy Carnegie Mellon University.

Nomad rover in Antarctica, 1999. Copyright Carnegie Mellon University

Image: CSIRO



Sales of Robots in North America in Millions of USD
Millions of US Dollars
2000
1500
1000
500
0
1060
1160
904
1070
895
569
846
1170
1480
1390
1500
1600
1680
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016



Labor Cost Savings from Adoption of Industrial Robots
35
30
25
20
15
10
5
0
33
25
24
22
22
21
21
20
18
18
16
South Korea
Japan
Canada
United States
Taiwan
United Kingdom
Germany
Australia
China
Czech Republic
Global total

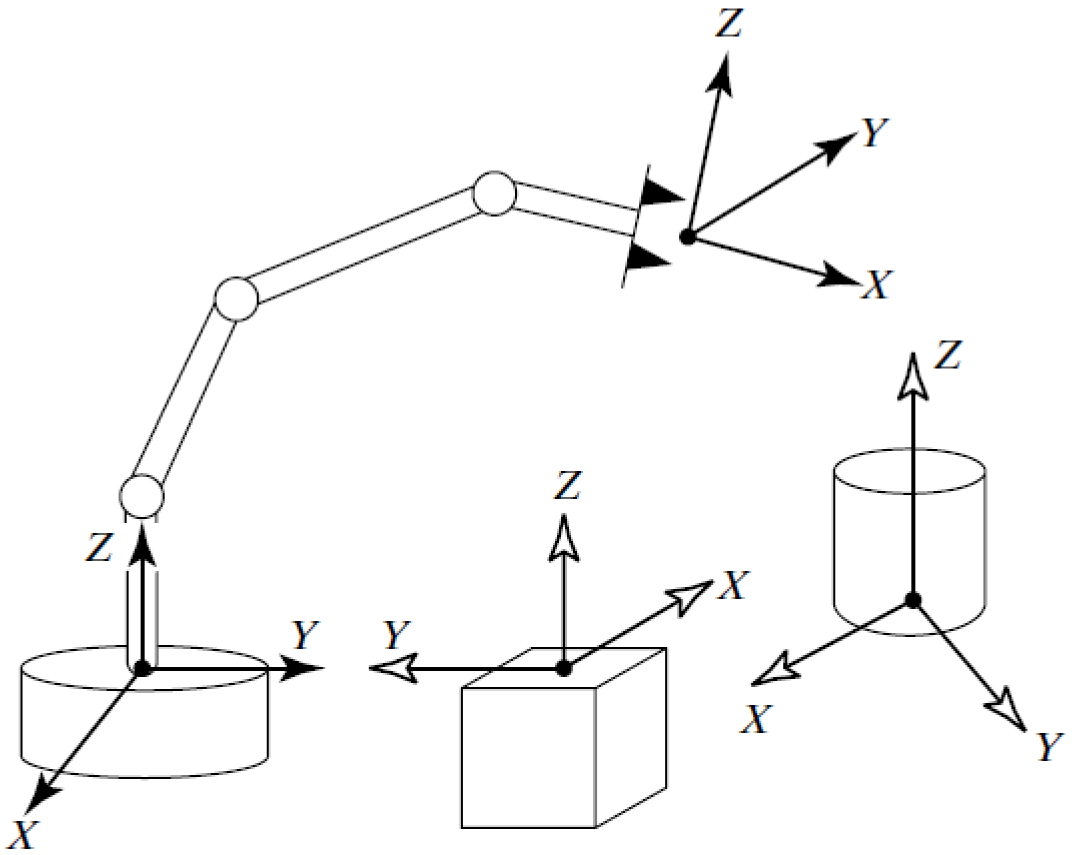
Group Discussion (In-class assignment)

Will be discussed in class.

Time: 10 minutes
Word Count: 50–100 words
Answers should be submitted in ilearn

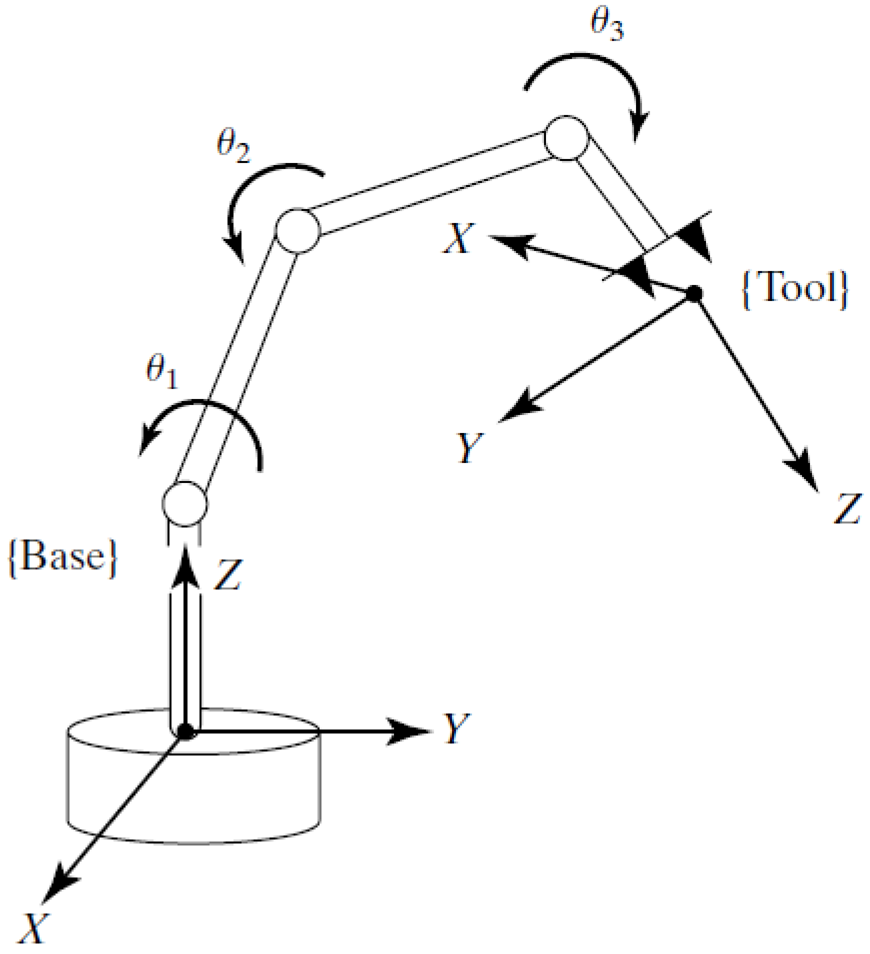
Robotics and Automation

Description of position and orientation (chapter 2)



Coordinate systems or ‘‘frames’’ are attached to the manipulator and to objects in the environment

Forward kinematics of manipulators (chapter 3)

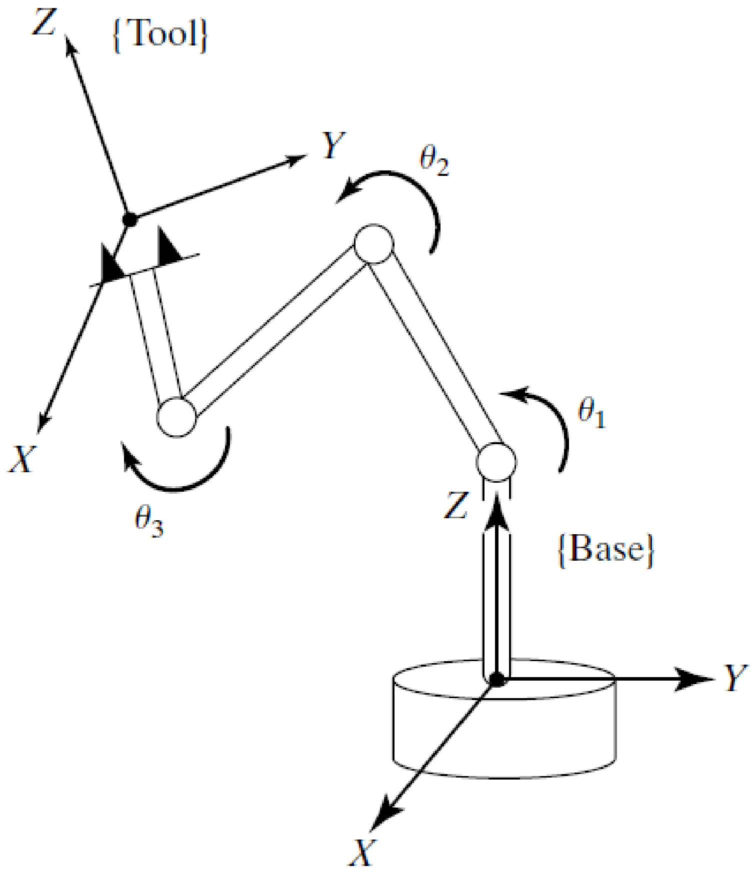


Kinematics is the science of motion that treats motion without regard to the forces which cause it.

Within the science of kinematics, one studies position, velocity, acceleration, and all higher order derivatives of the position variables (with respect to me or any other variable(s)). Hence, he study of the kinematics manipulators refers to all the gometrical and time-based properties of the motion.

Kinematic equations describe the tool frame relative to the base frame as a function of the joint variables.

Inverse kinematics of manipulators (chapter 4)

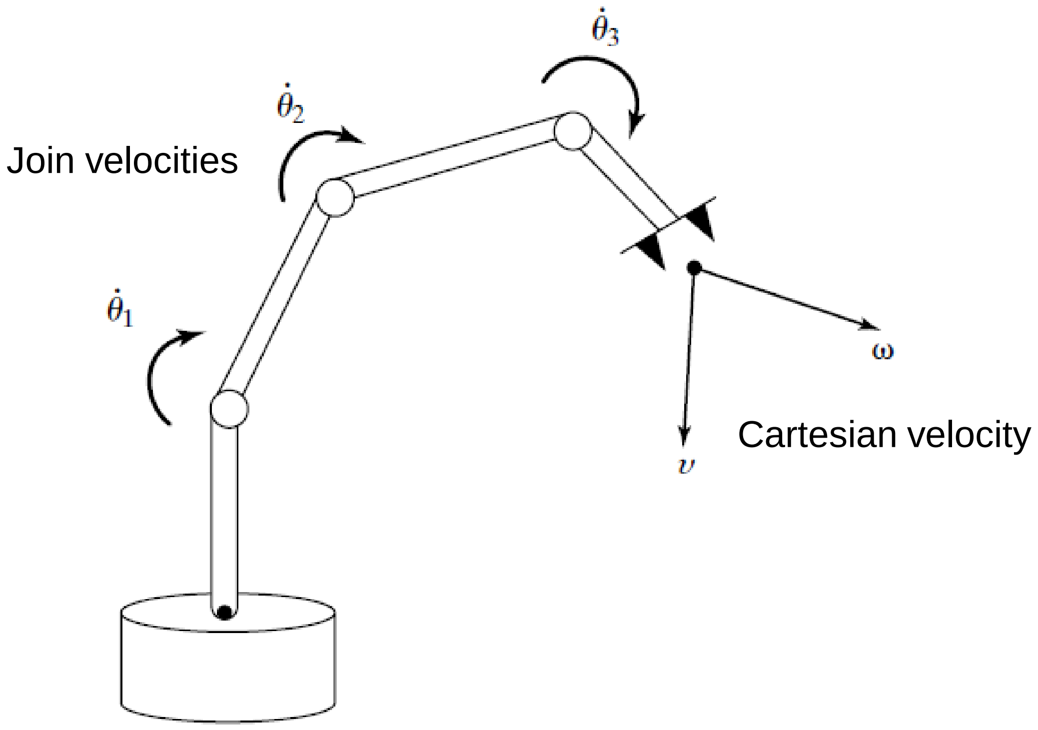


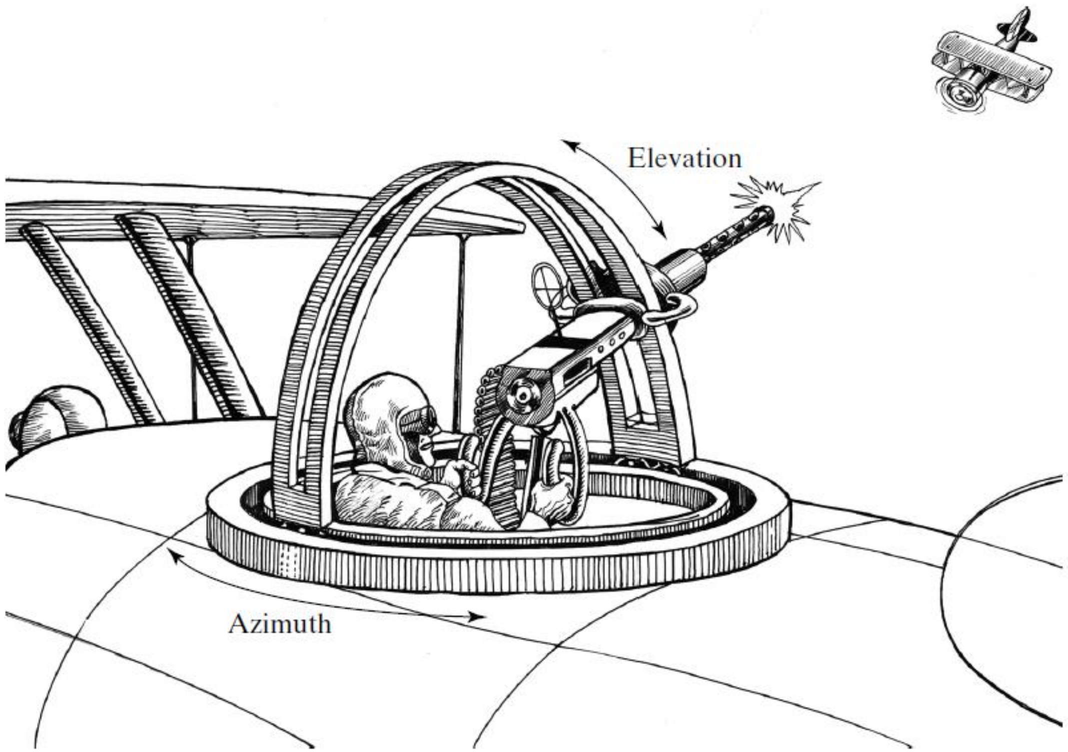
inverse kinematics: is used when we aim to use a given position and orientation of the end-effector of the manipulator to calculate all possible sets of joint angles that could be used to attain
this given position and orientation.

For a given position and orientation of the tool frame, values for the joint variables can be calculated via the inverse kinematics.

Velocities, Static Force and Singularities (chapter 5)

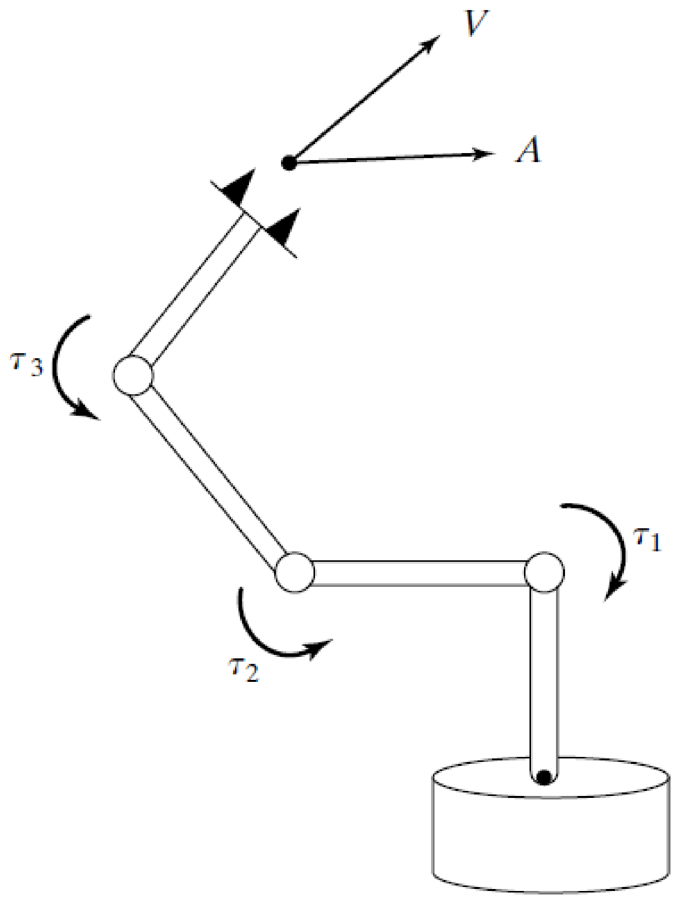
The geometrical relationship between joint rates and velocity of the end-effector can be described in matrix called Jacobian





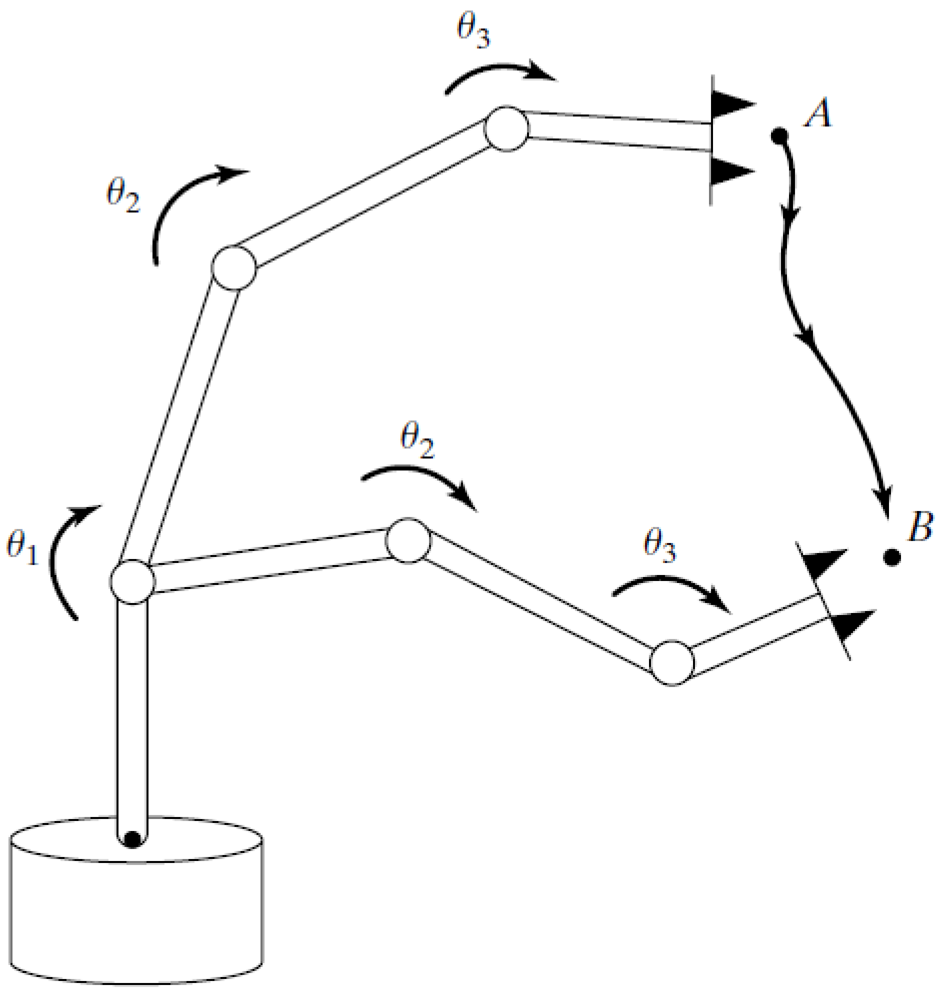
Dynamics (chapter 6)

Dynamics is a huge field of study devoted to studying the forces required to cause motion.



The relationship between the torques applied by the actuators and the resulting motion of the manipulator is embodied in the dynamic equations of motion.

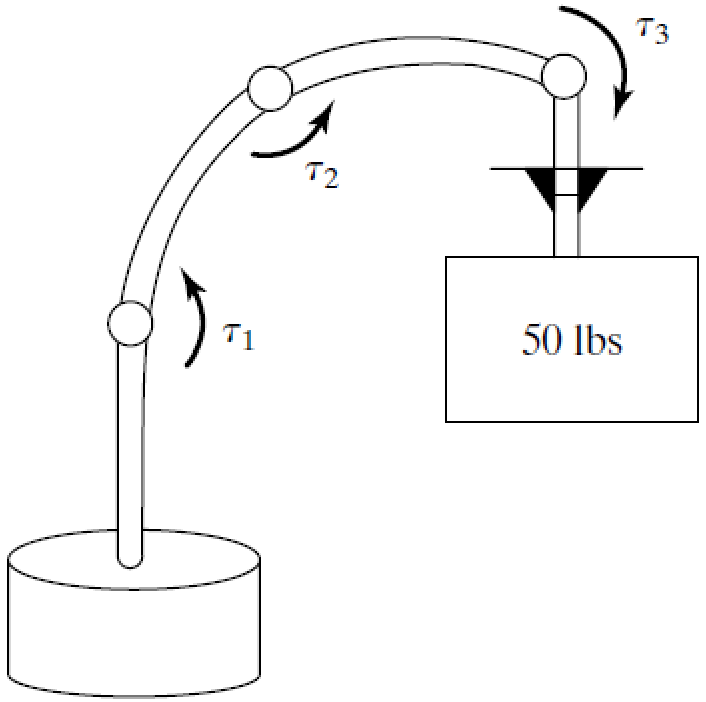
Trajectory Generation (chapter 7)



A common way of causing a manipulator to move from here to there in a smooth, controlled fashion is to cause each joint to move as specified by a smooth function of time. Commonly, each joint starts and ends its motion at the same time, so that the manipulator motion appears coordinated. Exactly how to compute these motion functions is the problem of **trajectory generation**.

Manipulator design and sensors

The design of mechanical manipulator must address issues of actuator choice, location, transmission, stiffness sensor location and more



Basic Matrix Operations

Basic Matrix Operations

<u>Matrix</u> – a rectangular array of numbers, variables, and both

<u>Order (dimensions)</u> – describes the number of rows and columns in a matrix

$$\begin{array}{rl} \begin{array}{r}\text{Row 1}\\ \text{Row 2}\end{array} & \begin{bmatrix} 2 & 4 & 5 & 6 \\ 3 & 7 & 8 & 10 \end{bmatrix} \\ & \begin{array}{cccc}\text{Column 1} & \text{Column 2} & \text{Column 3} & \text{Column 4}\end{array} \end{array}$$

This is a 2 x 4 matrix.

Rows Columns

Square matrix – a matrix, where the rows and columns are equal

$$\begin{pmatrix} 23 & 65 \\ 12 & -52 \end{pmatrix}$$

Column matrix – a matrix made up of just one column and any number of rows

$$\begin{pmatrix} 12 \\ 14 \\ 62 \end{pmatrix}$$

Row matrix – a matrix made up of just one row and any number of columns

$$\begin{pmatrix} 121 & 145 & 324 & 365 \end{pmatrix}$$

Adding and subtracting matrices – (matrices of the same dimensions can be added or subtracted) add or subtract the element of the first matrix by the element of the second matrix in the same position and the answer goes in that same position in the matrix that is representing the answer.

$$\begin{pmatrix} 2 & 3 \\ -6 & 7 \end{pmatrix} + \begin{pmatrix} 4 & -5 \\ 8 & 9 \end{pmatrix} = \begin{pmatrix} 2+4 & 3+-5 \\ -6+8 & 7+9 \end{pmatrix}$$

$$= \begin{pmatrix} 6 & -2 \\ 2 & 16 \end{pmatrix}$$

Main diagonal – the elements whose row number and column number are the sam

$$\begin{pmatrix} 1 & 2 & 3 & 4 \\ 5 & 6 & 7 & 8 \\ 9 & 10 & 11 & 12 \\ 13 & 14 & 15 & 16 \end{pmatrix}$$

Zero matrix – a matrix of any dimensions made up of all zeros

$$\begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix}$$

Scalar Multiplication – (think Distributive Property for Matrices) the element of the matrix are multiplied by a value outside of the matrix

$$5\begin{pmatrix} 8 & 23 \\ -11 & 16 \end{pmatrix} = \begin{pmatrix} 40 & 115 \\ -55 & 80 \end{pmatrix}$$

Matrix Multiplication – In order to multiply two matrices the columns of the first matrix must be equal to the rows of the second matrix.

$$\begin{array}{cc} [A] & \times \quad [B] \\ (m \times k) & (k \times n) \end{array}$$

i. Matrix size consistency: For the multiplication to be possible, the columns of the left matrix must be equal to the rows of the right matrix. If the left matrix size is NxM, and the right matrix size is MxR, then the resulting matrix will be NxR.

When doing word problems, make sure the labels of the rows and columns you are multiplying match as well as the numbers.

Matrix Multiplication

$$K = \begin{bmatrix} k_{11} & k_{12} & \cdots & k_{1m} \\ k_{21} & k_{22} & \cdots & k_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ k_{n1} & k_{n2} & \cdots & k_{nm} \end{bmatrix}^{n \times m}$$

, and

$$P = \begin{bmatrix} p_{11} & p_{12} & \cdots & p_{1r} \\ p_{21} & p_{22} & \cdots & p_{2r} \\ \vdots & \vdots & \ddots & \vdots \\ p_{m1} & p_{m2} & \cdots & p_{mr} \end{bmatrix}^{m \times r}$$

$$A * B = \begin{bmatrix} 2 & 3 & 4 \\ 3 & 4 & 5 \\ 5 & 1 & 6 \end{bmatrix} * \begin{bmatrix} 2 & 8 & 1 \\ 3 & 0 & 9 \\ 1 & 4 & 10 \end{bmatrix} = \begin{bmatrix} 17 & 32 & 69 \\ 23 & 44 & 89 \\ 19 & 64 & 74 \end{bmatrix}$$

$$B * A = \begin{bmatrix} 2 & 8 & 1 \\ 3 & 0 & 9 \\ 1 & 4 & 10 \end{bmatrix} * \begin{bmatrix} 2 & 3 & 4 \\ 3 & 4 & 5 \\ 5 & 1 & 6 \end{bmatrix} = \begin{bmatrix} 33 & 39 & 54 \\ 51 & 18 & 66 \\ 64 & 29 & 84 \end{bmatrix}$$

Transpose – (A^T) of the matrix A is the matrix obtained by interchanging the rows and columns of matrix A.

$$A = \begin{bmatrix} 1 & 2 & 3 \\ 4 & 5 & 6 \end{bmatrix} \qquad A^T = \begin{bmatrix} 1 & 4 \\ 2 & 5 \\ 3 & 6 \end{bmatrix}$$

The transpose function is in the Matrix catalog, MATH column and the second choice down.

Inverse – we use the inverse of a matrix when we need to divide it is denoted as A^{-1}

Identity Matrix – this acts like the number one for matrices, denoted with a capital I. This matrix must be a square matrix and have the number one in the main diagonal and 0's everywhere else.

Example: $\begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}$ or $\begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}$

End of week one