Stony Brook University

MEC 529
Introduction to Robotics: Theory and Applications

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Lecture Outline

- Course Overview and Administrative Information
- A Brief Overview of Robotics
- An Example (2R Robot)
- Position Kinematics of Rigid Bodies

Course Overview

- Topics that are fundamental to the subject of robotics.
  - Kinematics of Robotic Systems
  - Dynamics of Robotic Systems
  - Control of Robotic Systems
  - Sensing and Sensor Data Fusion in Robotic Systems
  - Planning in Robotic Systems
- We will cover different types of robotic systems, namely
  - Articulated Manipulators
  - Mobile Robots

Course Prerequisites

- Knowledge in undergraduate level kinematics and dynamics in ME.
- Ability to program competently in Matlab.
  - I will not debug your codes during office hours or by email.
- Basic knowledge of linear algebra and calculus. You should be comfortable with
  - Concepts of Eigenvalues, eigenvectors.
  - Concepts of limit, continuity, differentiability, partial derivatives, finding maxima and minima of functions, differential equations and integration.
  - Solving a second order differential equation using Matlab.

Class Information

- Instructor:
  - Nilanjan Chakraborty, 212 Heavy Engineering Bldg.,
  - Email: nilanjan.chakraborty@stonybrook.edu
- Lecture Hours:
  - Tuesday, 1:00 PM – 3:50 PM
  - Frey Hall 201.
- Office Hours:
  - Tuesday, 11:00 AM – 12:30 PM.
  - Thursday, 1:00 PM – 2:30 PM.
  - Alternate time can be arranged by email appointment.
- Text Books:
  - K. M. Lynch and F. C. Park, *Modern Robotics: Mechanics, Planning, and Control*, Cambridge University Press.
  - J. J. Craig, *An Introduction to Robotics: Mechanics and Control*, 3rd Edition, Addison Wesley.
  - R. M. Murray, Z. Li, and S. S. Sastry, *A Mathematical Introduction to Robotic Manipulation*, CRC Press.
  - S. Lavalle, *Robot Motion Planning*, Cambridge University Press.

Assignments, Projects, and Exam

- Assignments:
  - Weekly homeworks (30% of total grade).
  - 1 Paper Critique (5% of total grade).
  - Assignments will be due in class.
  - 2 late days are allowed on every assignment. You will be penalized 20% of the grade for late submission.
    - Assignments will NOT be accepted after the late days expire.
- Exam:
  - 1 midterm take home exam (35% of total grade).
  - Tentative Date: March 27th, 2018.
- Projects:
  - 1 final project (30% of total grade).
  - Groups of 2 to 3 students.
  - There will be a final project presentation. Presentation has to be made by all students.
  - 2 reports for the project (one for project proposal and one on final).

Grades

Not a curve – accumulation of your course work, as follows:

A (100-90) A- (89-85) B+ (84-80) B (79-75)

B- (74-70) C+ (69-65) C (64-60) F (59 or below).

Blackboard

- All homework assignments and solutions will be posted on the Blackboard course account. For problems logging in, go to the helpdesk in the Main Library SINC Site or the Union SINC Site, you can also call: 631-632-9602 or e-mail: helpme@ic.sunysb.edu

- I will use email and blackboard exclusively to communicate with you off class. It is your responsibility to make sure that your email id is a current one on the blackboard system. I suggest that you use a university email id for this class; it is free and official. I am not responsible for the emails not delivered to your commercially available email accounts.

Academic Honesty

- The campus policies on academic honesty are available on the Web (http://www.stonybrook.edu/commcms/academic_integrity/policies.html)
- Academic dishonesty is an extremely serious offense and will not be tolerated in any form.
- Examples include, *but are not limited to*, copying class assignments including homework, reports, and other submitted materials; copying or otherwise communicating answers on exams with other students;
- You can discuss about homework, but the submission should be your own work. Copying code for homeworks or exams are not allowed. I will use software to compare codes. Any violation will be taken seriously.
- Academic dishonesty violates both the ethical and moral standards of the Engineering profession and all infractions related to academic dishonesty will be prosecuted to the fullest via the CEAS CASA committee.

ADA

- If you have a physical, psychological, medical or learning disability that may impact your course work, please contact Disability Support Services, ECC (Educational Communications Center) Building, room 128, (631) 632-6748.
- They will determine with you what accommodations are necessary and appropriate. All information and documentation is confidential. Students requiring emergency evacuation are encouraged to discuss their needs with their professors and Disability Support Services.
- For procedures and information, go to the following web site http://studentaffairs.stonybrook.edu/dss/.

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What is a Robot?

- Origin of the word “robot”
  - Czech word “robota”– labor, “robotnik” – workman
  - 1923 play by Karel Capek – Rossum’s Universal Robots
- There is no agreed upon definition of a robot
  - Robotics Institute of America: A robot (industrial robot) is a reprogrammable, multifunctional manipulator designed to move materials, parts, tools, or specialized devices, through variable programmed motions for the performance of a variety of tasks.
- To qualify as a robot, a machine must be able to:

1) Sense and perceive: get information about its surroundings and itself.
2) Move itself and/or other objects in the environment: can do locomotion or manipulation
3) Re-programmable: can do different things
4) Function autonomously and/or interact with human beings

Components of a Robot

- Robots are typically composed of mechanical/electrical/electronic/software sub-systems.
- Operate in a Sense-Plan-Act loop.
- Robots usually consist of the following subsystems:
    - Physical Embodiment or Mechanical Structure (Mechanical)
    - Sensing System (Mechanical/Electrical/Electronic)
    - Actuating System (Mechanical/Electrical)
    - Planning/Controller System (Electrical/Electronic/Software)
    - Communication System (Electronic/Software)
    - Energy System (Electrical/Electronic)

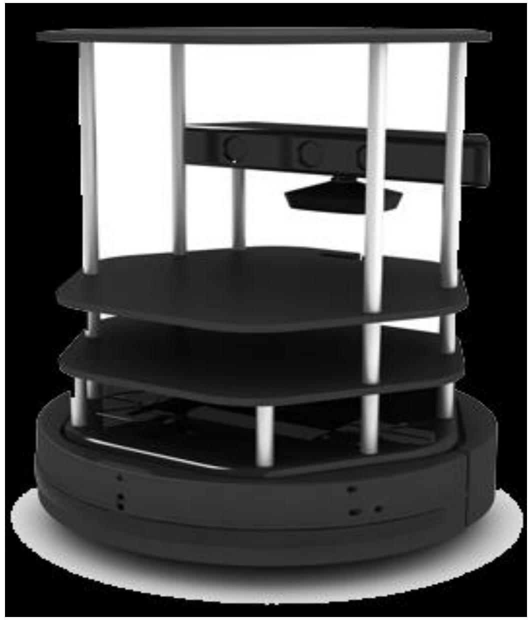
Our Goal:

- Understand how to use the **sensing**, **planning**, and **actuation** system to **move** the robot so as to accomplish any desired task.

Different Types of Robots - I

Robots with manipulators and different locomotion systems.

Different Types of Robots - II



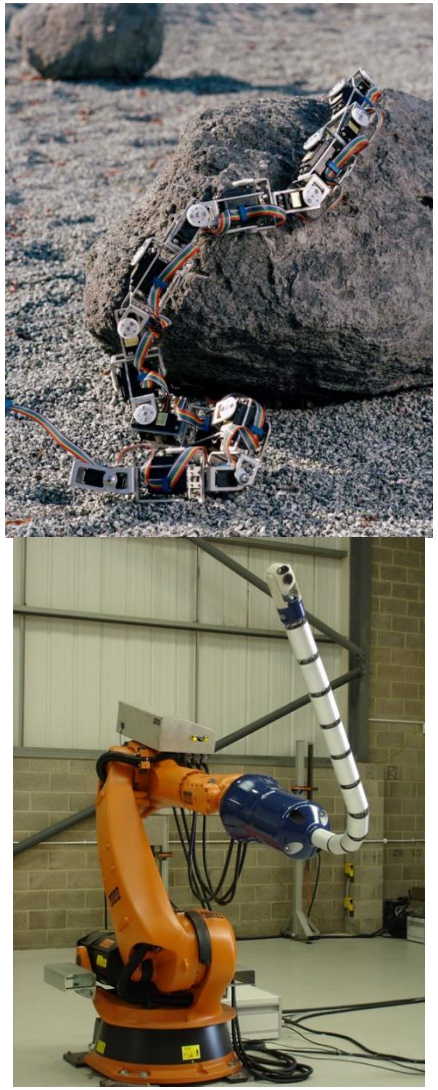
Indoor Robots – Designed to move on flat surfaces.

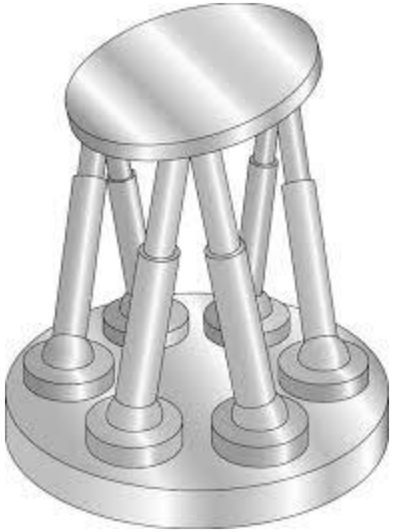
Outdoor Robots – Designed to move on uneven surfaces.

Different Types of Robots - III

Aerial Robot

Underwater Robot





Stewart Platform

Medical Robot

Snake Robots

End Effector Systems: Robot Grippers

5-fingered hand with 3 links per finger

3-fingered hand with 2 links per finger

2-fingered hand

Much of the mechanical design and analysis for robotics systems can be reduced to design and analysis of

- Open loop serial chain mechanisms.
- Closed loop mechanisms.

Mechanical Systems of a Robot: Analysis

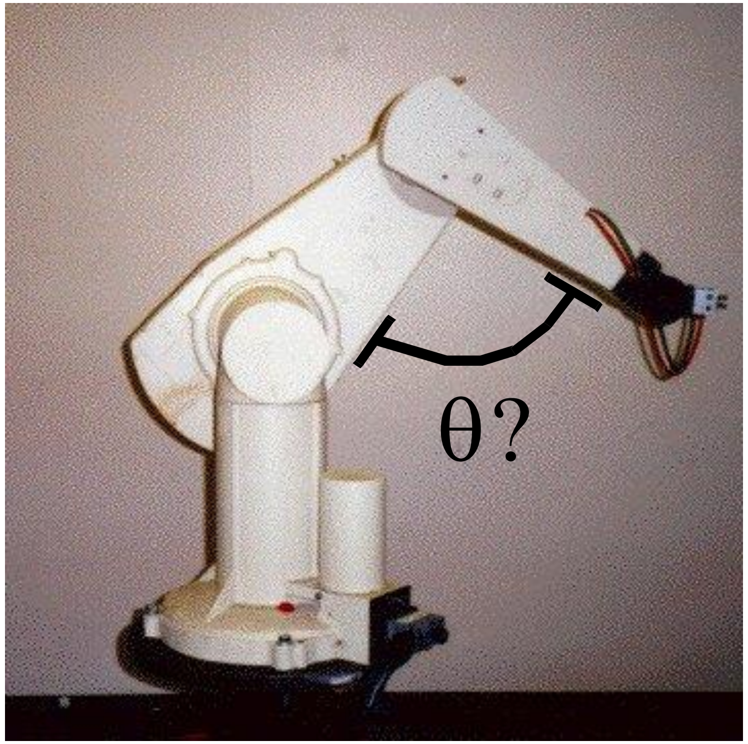
- Kinematics: Analysis of motion of a robot (more generally any object) with no regard to the forces acting on the robot.
  - Position Kinematics
  - Velocity Kinematics
  - Acceleration and higher order derivatives of position
- Dynamics: Analysis of motion of a robot (more generally any object) while considering all the forces and moments acting on the body.
- There are two types of problems that we will be interested in (in both kinematics and dynamics)
  - Direct Problems
  - Inverse Problems

Robot Sensing System

- Sensor - an electrical/mechanical/chemical device that maps an environmental/robot attribute to a quantitative measurement
- Mostly, sensors are based on a *transduction principle* - conversion of energy from one form to another
- Types of Sensors
  - Exteroceptive: senses external world
    - where is something ?
    - how does it look ? (camera, laser rangefinder)
  - Proprioceptive: senses self
    - where are my hands ? (encoders)
    - where am I in the room or building?
    - am I balanced ? (gyroscopes)
    - what is my charge level?

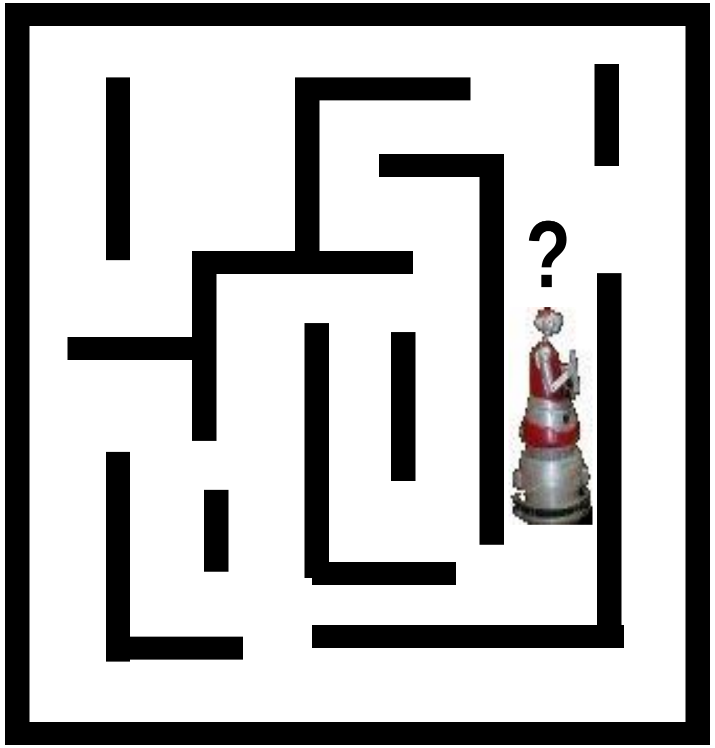
Need for Robot Sensors

What is the angle of my arm?



Internal State Information

Where am I in the world?



Localization

Gathering Task related information
Where is the crop line?

Autonomous Harvesting

Types and Examples of Robot Sensors

- Active
  - send signal into environment and measure interaction of signal w/ environment, e.g., laser range finder, sonar.
- Passive
  - record signals already present in environment, e.g., video cameras

Common Sensors:

- Electromagnetic spectrum: Cameras (visible light, infra-red), Laser Range finders, RGBD cameras.
- Sound Wave: Ultrasonic Sensors
- Motion based: Force/Torque Sensors, Joint Encoders, IMUs.
- Task related sensors: Temperature sensor, Odor sensor, Light sensor.

Example Robot Sensors

Joint Encoder

SICK Laser Range Finder on a mobile robot

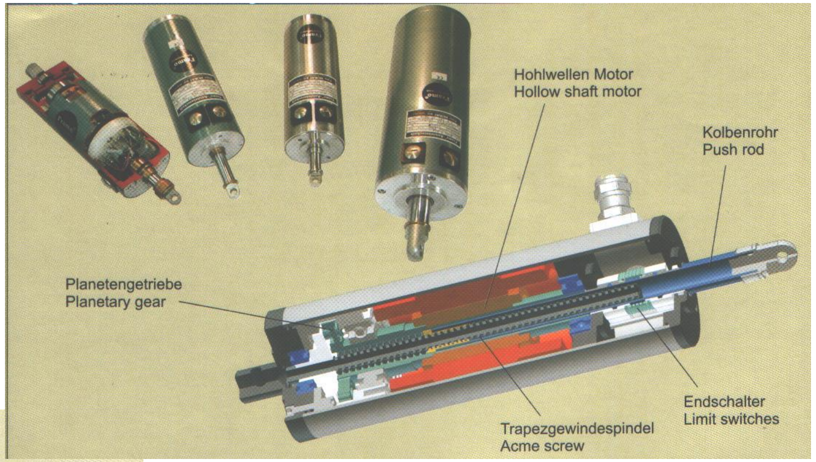
RGBD camera

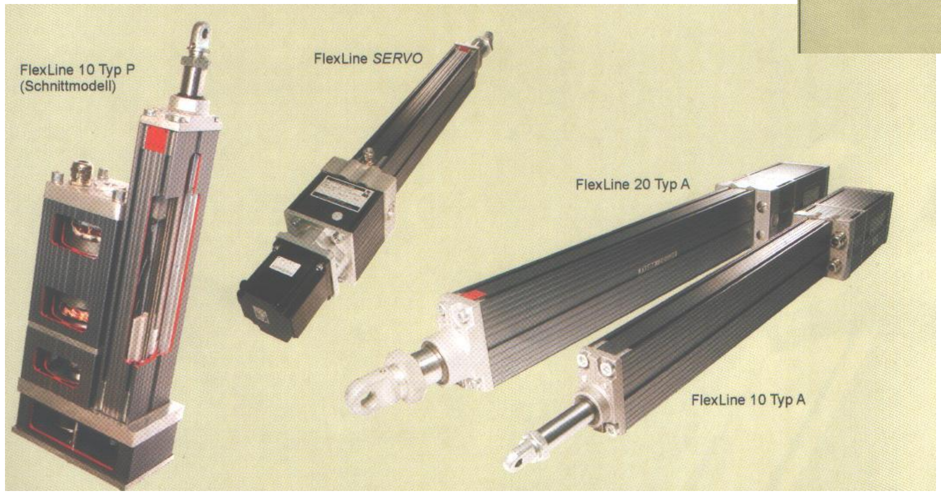
Sensor Data Analysis

- Given the (noisy) sensor data how does the robot estimate its own state?
  - Given the joint encoder values for a manipulator, what is the configuration of the end effector?
  - Given the joint encoder values for the rotation of the wheels of a mobile robot, what is its current position and heading?
- Given the (noisy) sensor data how does the robot extract information about its environment?

Robot Actuation System

- Actuators of robots are analogous to muscles of humans/animals.
- They produce mechanical movement (rotational as well as linear).
- Types of actuators:
  - Electric motors (DC servomotors, stepper motors),
  - Hydraulic systems
  - Pneumatic systems
  - Piezoelectric
  - magnetic
  - ultra sound
  - Shape memory alloy



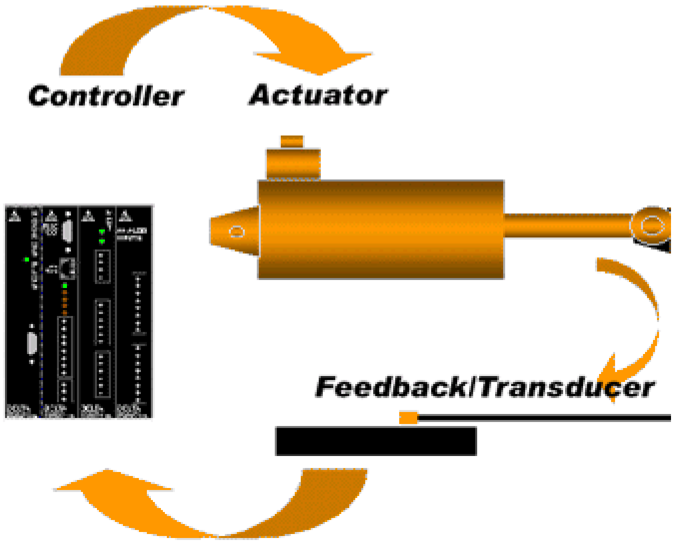


Problem: Actuator choice

- Common considerations in selecting an actuator:
  - How precisely does the driven mechanism need to be controlled?
  - What is the range of motion required? (especially for linear actuators)
  - What is the magnitude of force/torque required at a joint?
  - How fast do the torques change?
  - What is the operating environment? (hazardous vs ordinary)
  - Cost considerations.

Robot Controllers

- Controllers direct a robot ``how" to move.
- Different types of control problem for robots
  - Position control
  - Trajectory control
  - Force control
  - Hybrid position/force control
- There are two controller paradigms
  - Open-loop controllers execute robot movement without feedback.
  - Closed-loop controllers execute robot movement and judge progress with sensors. They can thus compensate for errors.



- Our Goal: How does one design a controller for a manipulator for a given task?

Robot Planners

- Planners direct a robot ``where” to move?
  - Planners can be at different levels of hierarchy.
- Planning Problem: Given a task what are the set of actions that the robot should take (or set of sub-tasks that the robot should do)?
- Planning is a big field in AI. There are different questions of interest in planning.
  - How does one represent a task and a plan?
  - Given a task how does one compute a plan to perform the task?
  - How does one integrate the planner with the ``low-level” controller of the robot?
  - How does one integrate sensor information with planners?

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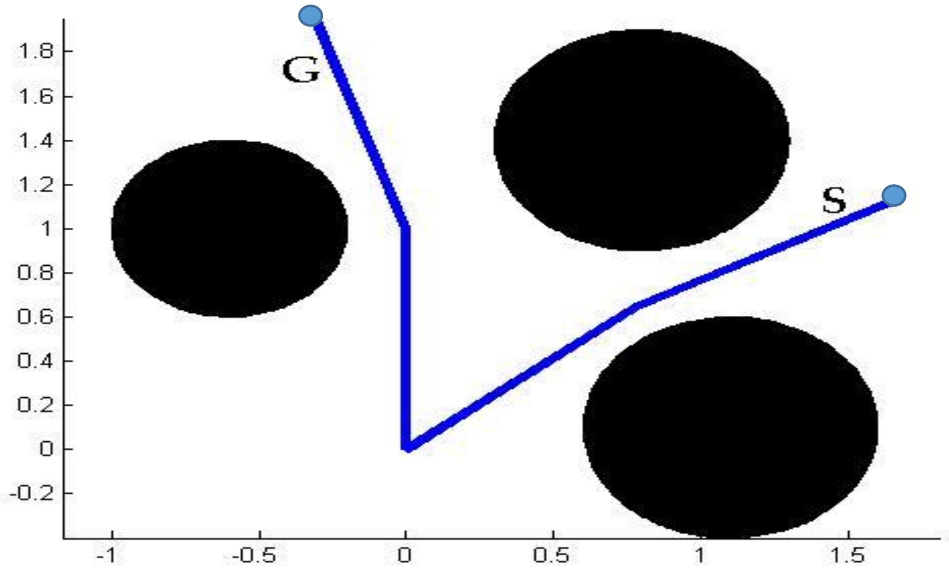
A Key Problem in Robotics

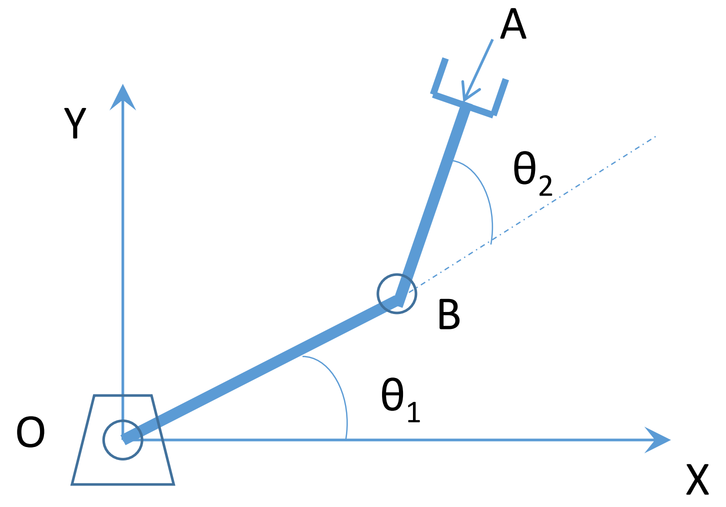
- How to reach a goal location? (ill-posed question)
  - Many specific instances of this question have to be solved by robots.
- Our Objective for the next few minutes: To study a very simple instance of the question above for the simplest possible robot and understand relevant sub-problems that must be solved.
- Problem Statement: How do we move the end effector of the 2R robot from start position, *S* , to goal position, G, while avoiding the obstacles (black regions in the figures)?



Position Kinematics

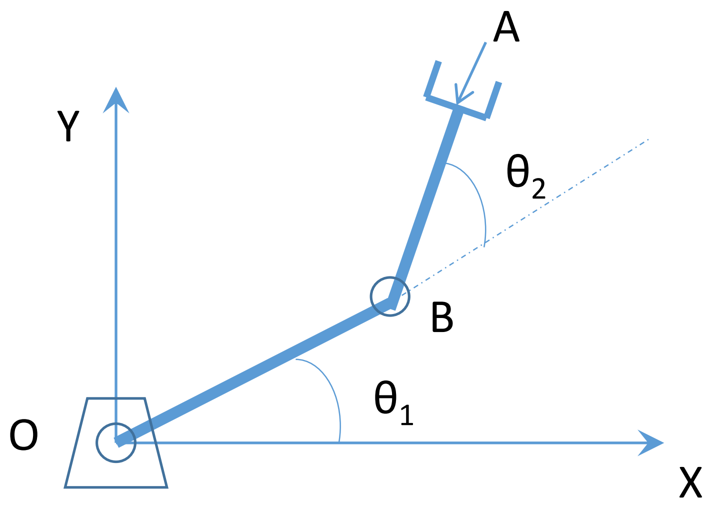
- **Direct Kinematics (DK)**: Given the joint angles of the robot, find the position of the point A.
- **Inverse Kinematics (IK)**: Given the position of the point A, find the joint angles of the robot.

- DK helps in computing where the end effector is by using joint encoders to sense the joint angles.
  - One utility (among many others) of DK is that it allows us to know if we have reached the goal or not.
- IK helps in computing the joint angles that the 2R robot has to be driven to so that the end effector point reaches the position G.



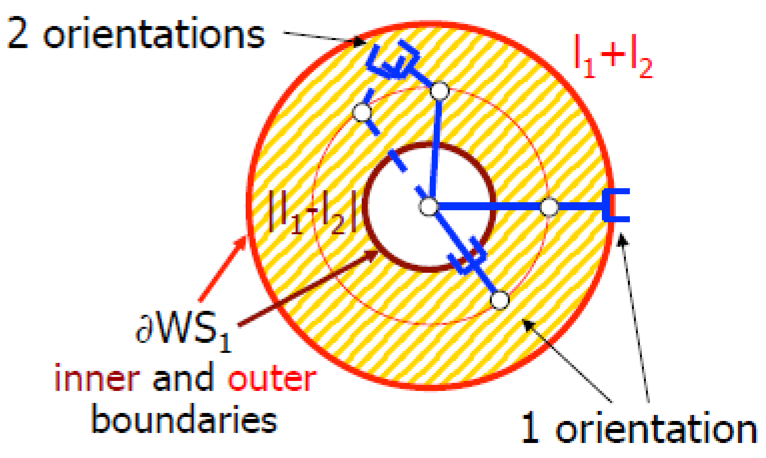
Differential Kinematics

- **Direct Velocity Kinematics**: Given the joint angle rates of the robot, find the velocity of the point A.
- **Inverse Velocity Kinematics**: Given the velocity of the point A, find the joint angle rates of the robot.



Workspace

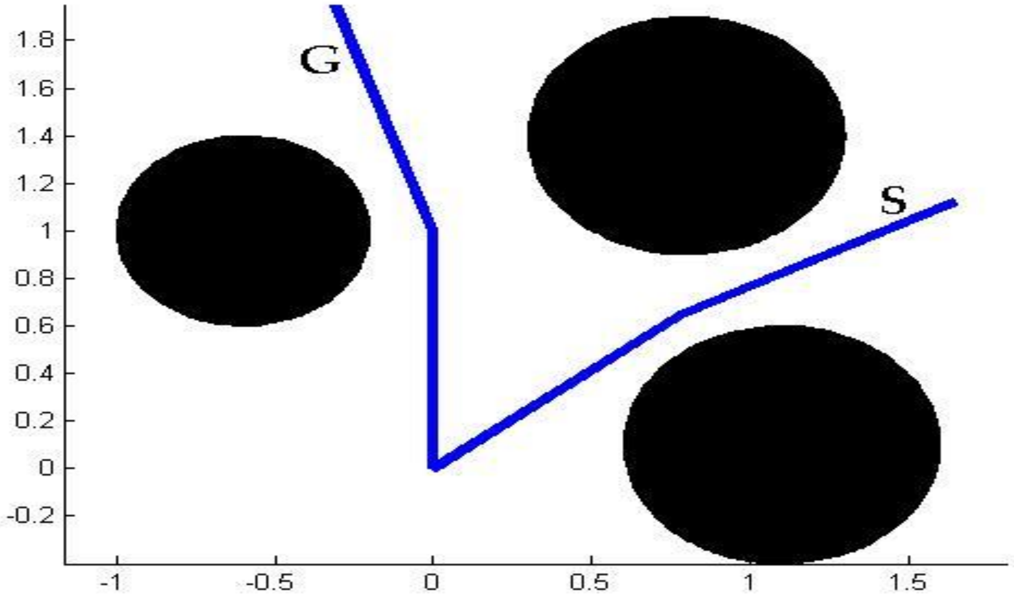
- Workspace is the set of all reachable positions and/or orientations by the end effector.
- Primary Workspace: Set of all positions that can be reached with at least one orientation
- Dexterous workspace: Set of all positions that can be reached with any orientation.
- What is the geometric description of the workspace of the 2R manipulator?

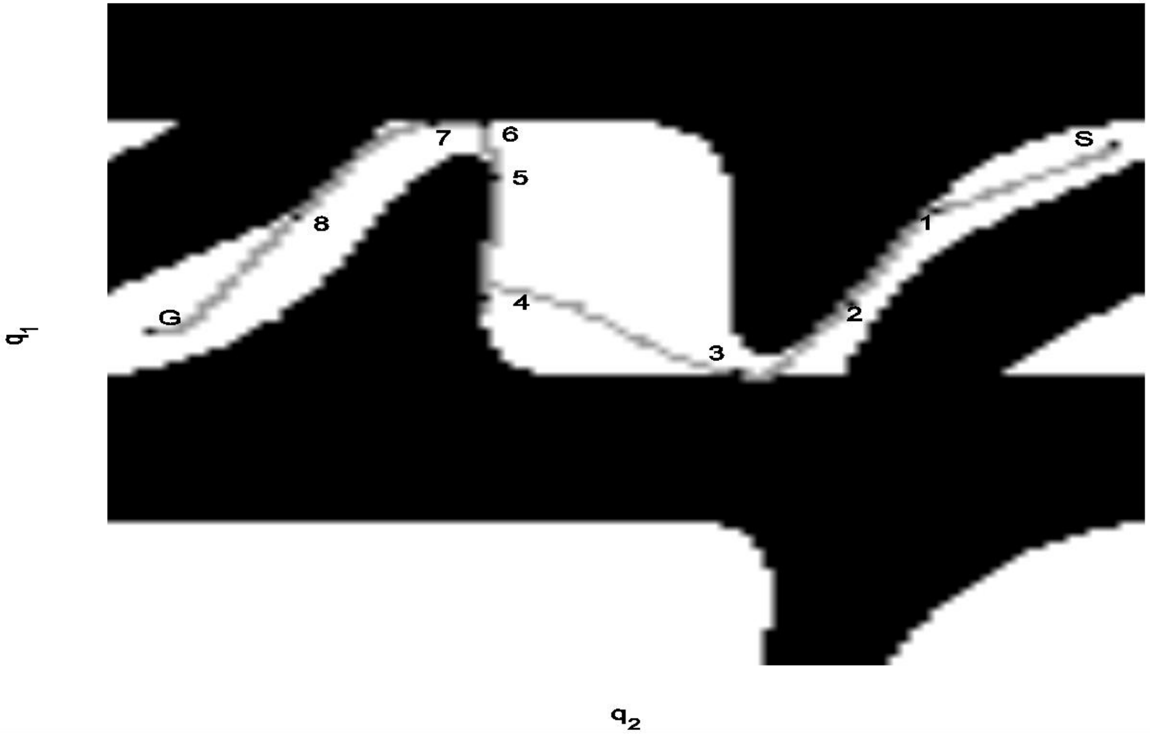


Configuration Space

- Each value of the parameters corresponding to the (Degree of Freedom) DoF of a kinematic chain or linkage system defines the configuration of the robot.
- Configuration space is the set of all configurations of the robot.
- Free configuration space is the set of all configurations of the robot in which it is not in collision with an obstacle.
- The motion planning problem of any robot can be converted to a motion planning problem of a point robot in the free configuration space.

Configuration Space Example





The 2-link robot shown on the left is a point
in the configuration space on the right. The black region
is the configuration space obstacle.

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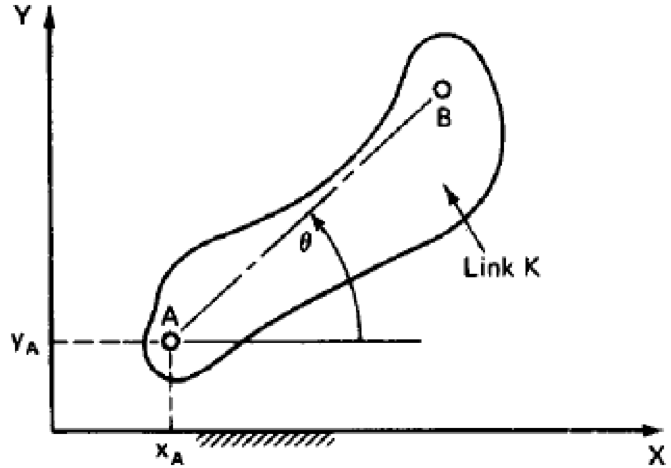
Point Mass and Rigid Body

- What is a point mass (or point)?
  - A point mass is an object whose dimensions are considered to be zero but it has non-zero mass.
  - It is an idealization of a physical system where the size of the system is ignored.
- What is a rigid body?
  - A rigid body is a set of points in which the *distance between any two given points remains the same* irrespective of the external forces exerted on it.
  - A rigid body is an idealization of a solid.

Degrees of Freedom (DoF)

- Degrees of Freedom of a point mass
  - The number of independent parameters required to describe the point.
  - For a point mass in the plane, DoF is 2.
  - For a point mass in 3D space, DoF is 3.
- Degrees of Freedom of a rigid body
  - The degrees of freedom of a rigid body is the number of *independent parameters* required to describe the body.
  - To locate each point of a rigid body in space, one needs to know a geometric description of the body and the independent parameters.
  - For a rigid body in the plane, DoF is 3.
  - For a rigid body in space, DoF is 6.



Atan2 versus Traditional Arctan

$$\operatorname{atan2}(y,x) = \begin{cases} \arctan\frac{y}{x} & x > 0 \\ \arctan\frac{y}{x} + \pi & y \geq 0, x < 0 \\ \arctan\frac{y}{x} - \pi & y < 0, x < 0 \\ +\frac{\pi}{2} & y > 0, x = 0 \\ -\frac{\pi}{2} & y < 0, x = 0 \\ \text{undefined} & y = 0, x = 0 \end{cases}$$

Here, range of the angle is between (-π, π).

Thank You!