

Workshop 1:

Introduction to Robotic Systems

Nicholas Ho

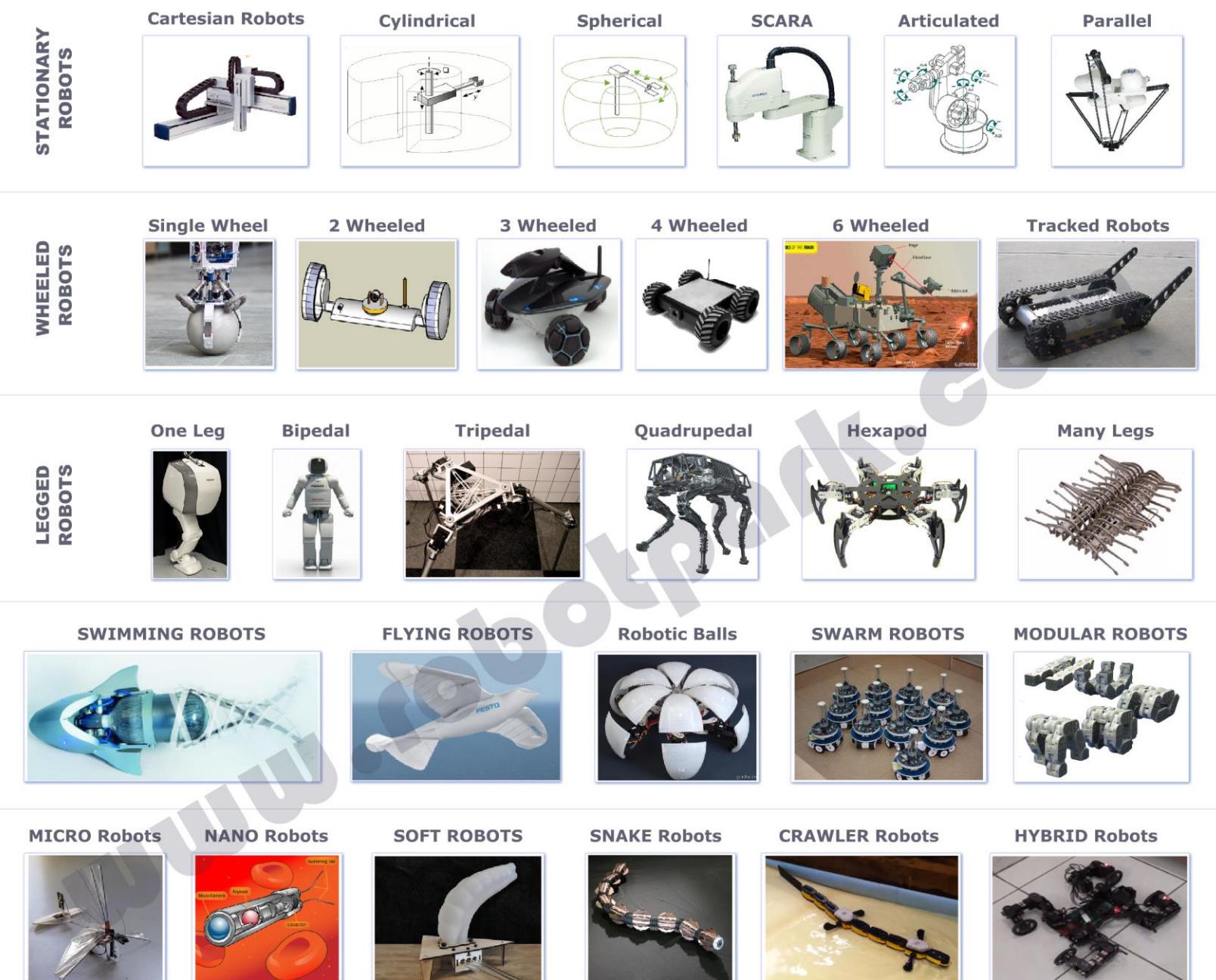
Objective(s):

1. Demonstrate usage of mechanism and control for robotic components

Topics

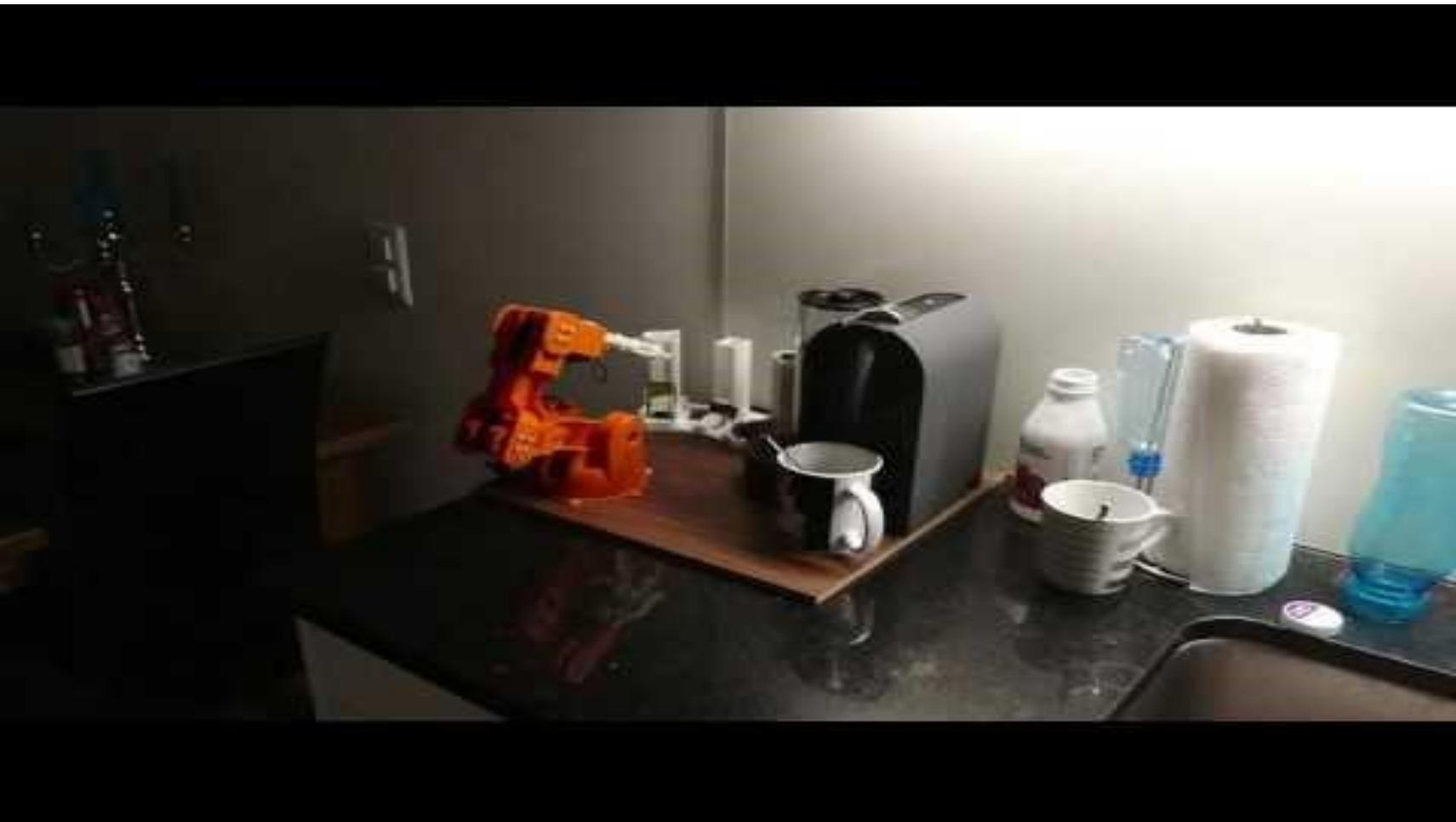
1. The working of a robotic arm
2. How to configure and control a robotic arm?
3. Introduction to ROS
4. Using ROS to Control Robots
5. Basic micro-management of the robotic arm
6. Group Work

All Types of Robots by Locomotion



Chapter 1: The working of a robotic arm

What is a Robotic Arm?

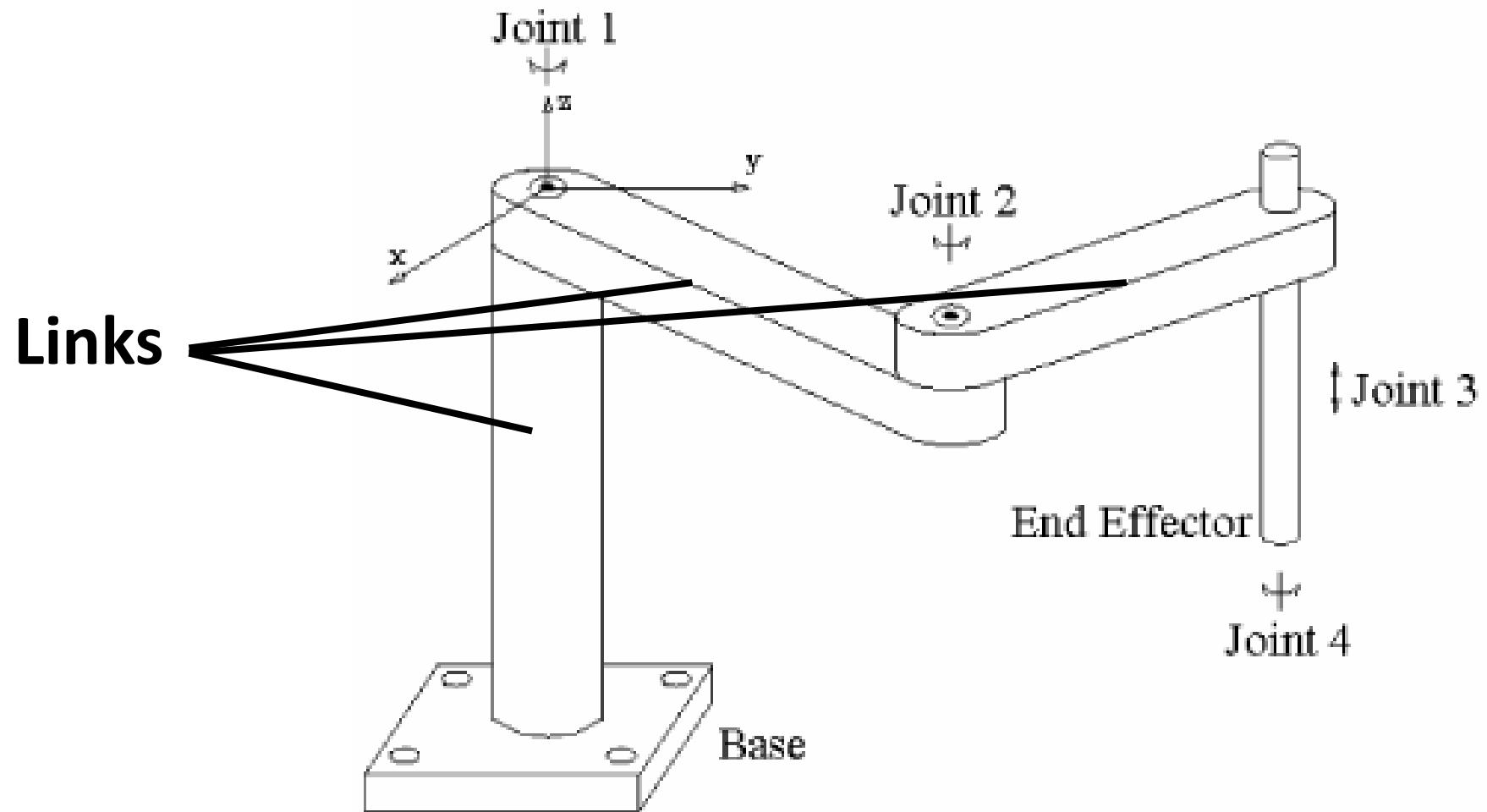


Source: https://www.youtube.com/watch?v=DA-0yz_O_u0

What is a Robotic Arm?

- An example of Robotic System
- A type of mechanical arm, with **similar functions to a human arm**
- **Each link is connected by joints**
- Either **rotational or translational** motion in each joint

Parts of a Robotic Arm



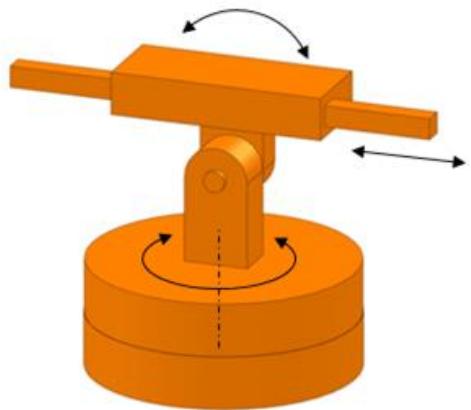
Many Types of Robotic Arm

Rectangular Arm Geometry
Cartesian Coordinates

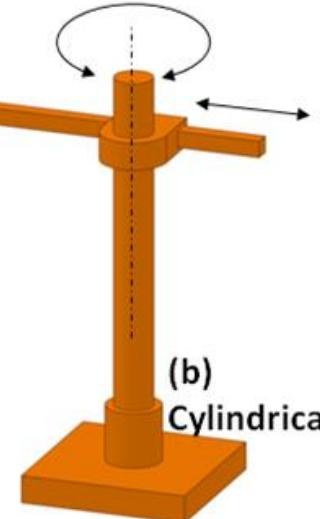


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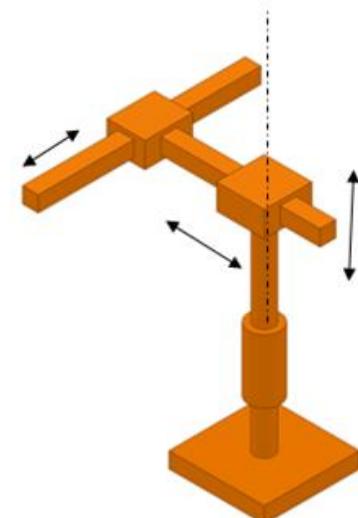
Many Types of Robotic Arm



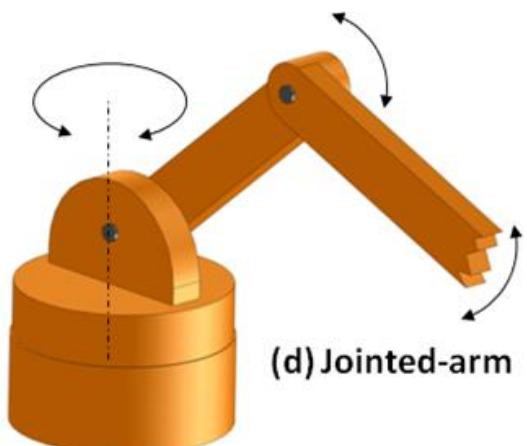
(a) Polar



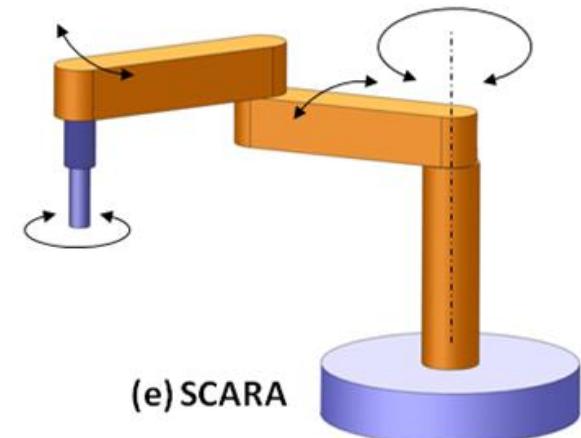
(b) Cylindrical



(c) Cartesian

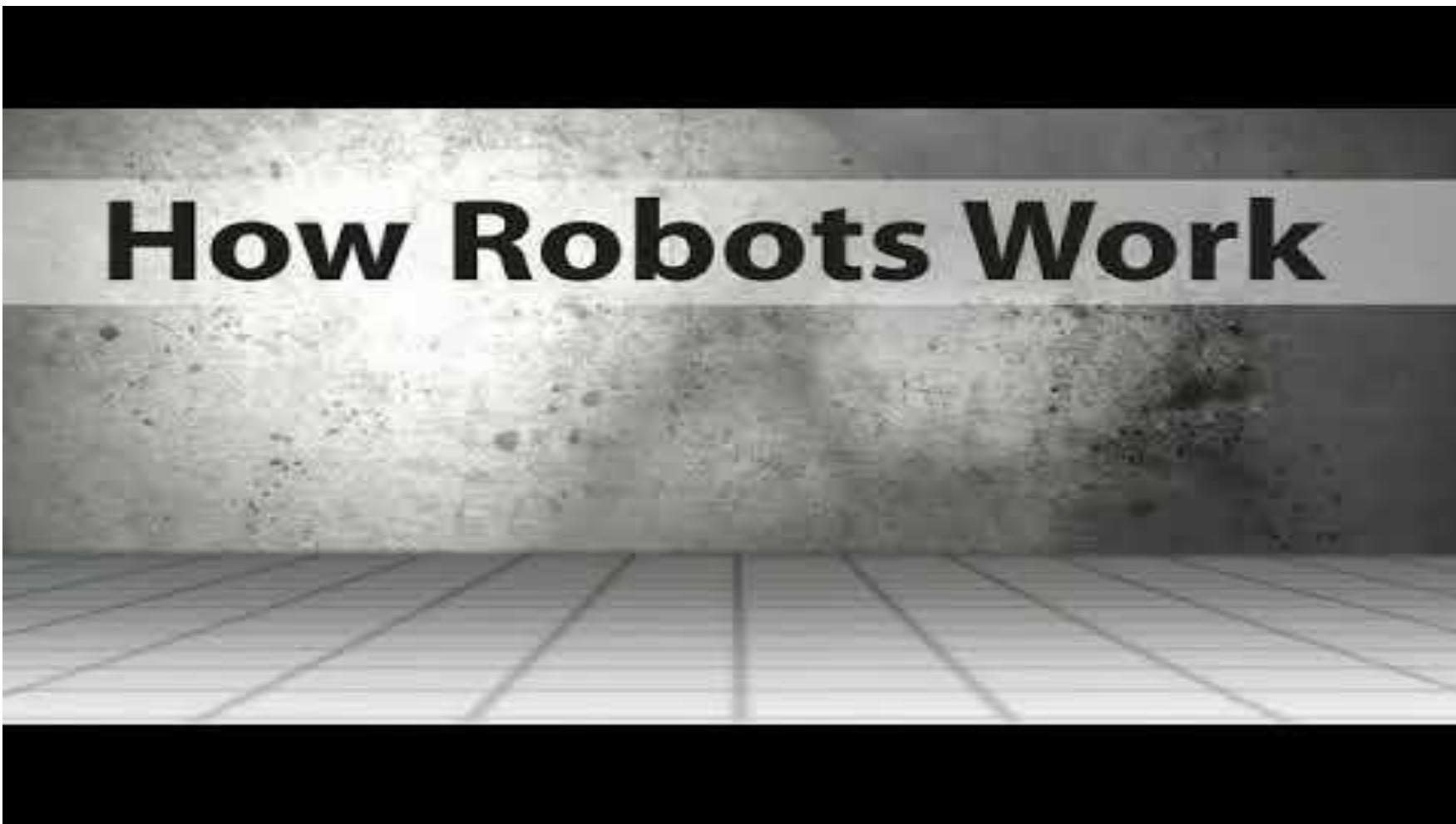


(d) Jointed-arm



(e) SCARA

Degrees of Freedom (DOF)

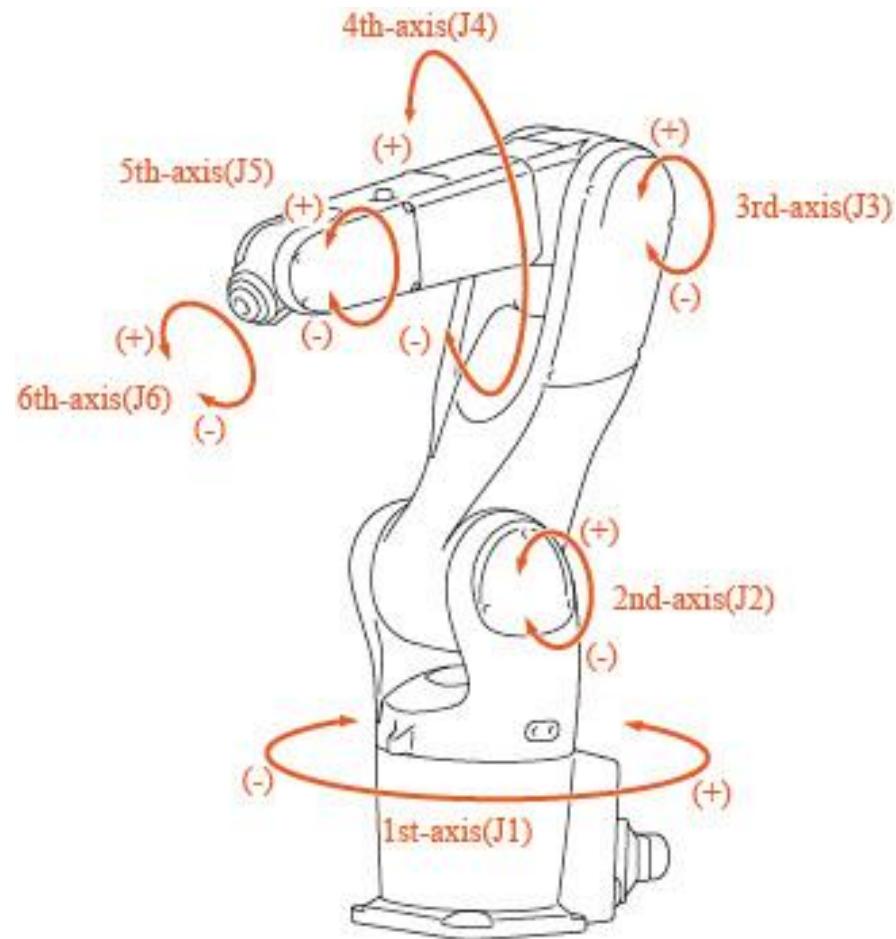


Source: <https://www.youtube.com/watch?v=sy7Yhp21mE4>

Degrees of Freedom (DOF)

- Defines how many directions the robot arm can move
- Each DOF is a joint on the arm (bending, rotating or translating motions)
- **No. of DOF = No. of actuators**

Degrees of Freedom (DOF)



What is a Servo Motor?

- A **simple DC motor** controlled for specific angular rotation with the help of additional servomechanism (closed-loop feedback control system)
- Main reason behind using a servo is that it **provides angular precision** (i.e. only rotate as much we want and then stop and wait for next signal to take further action)
- **Operates differently from standard electric motor**

What is a Servo Motor?



Source: <https://www.youtube.com/watch?v=gviUtLsHDtg>

Food for thought (Discussion Topic)

What is the main challenge that engineers face when building robotic systems?

Chapter 2: How to configure and control a robotic arm?

What is needed?

1. A **robotic arm** (purchased or self-made)
2. A **control software** (e.g. ROS, Arduino)
3. A **control board** (i.e. microcontroller)
compatible with the software
4. A **sensor shield** compatible with the software
and hardware (optional)

Example 1

Tinkerkit Braccio Robotic Arm
(will NOT be practiced for this course)

Introducing Tinkerkit Braccio Robotic Arm

- 6 DOF or 6-axis, Arduino controlled
- 6 Servo Motors at each joint:
 - Motor 1 – at base, rotate from left to right
 - Motor 2 – helps lower arm to move up/down
 - Motor 3 – helps upper arm to move forward/backward
 - Motor 4 – helps wrist to move forward/backward
 - Motor 5 – Rotates wrist in a circular movement
 - Motor 6 – Control the gripper



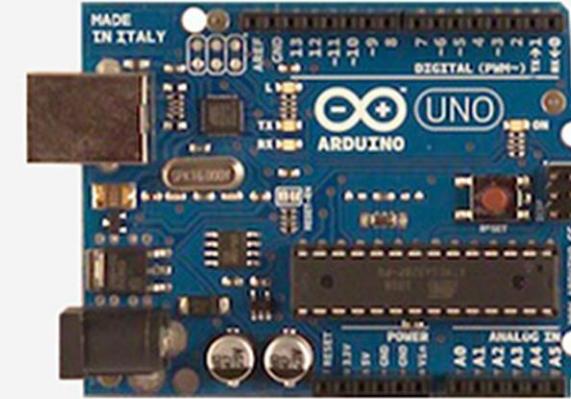
Introducing Arduino Software (IDE)



- Open-source
- **Supports C and C++;** requires basic programming skills
- Allows you to easily **write codes in your desktop/laptop** and **upload them to the control board**
- Software is compatible with any Arduino board

Introducing Arduino Boards

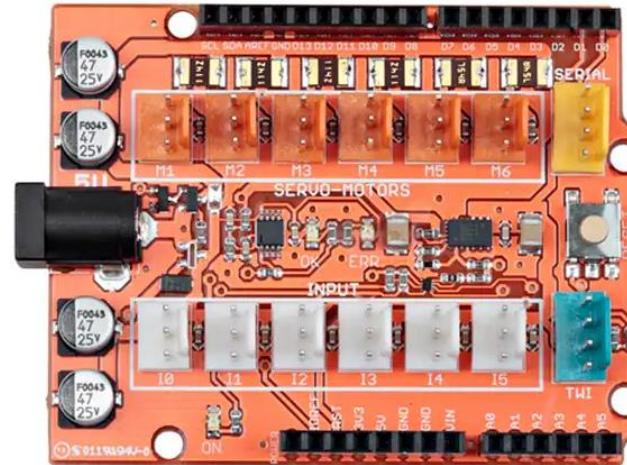
- A type of **microcontroller**
- **Hardware that reads inputs** (e.g. motor degrees, sensor readings) **and turn them into outputs** (e.g. activating motors)
- Comes in both **USB & Bluetooth versions**



Why Arduino?

- **Inexpensive** – Relatively inexpensive compared to other microcontroller platforms
- **Cross-platform** – Runs on Windows, Macintosh OSX, and Linux OS
- **Simple, clear programming environment**
- **Open source and extensible software/hardware**

Introducing TinkerKit Shield



- A type of **sensor shield**
- **Hardware that connects sensors and actuators directly to Arduinio**, without the use of any breadboard
- Compatible with Arduinio (an extension board) and the Braccio Robotic Arm

Example 2

Robotis OpenManipulator-X
robotic Arm

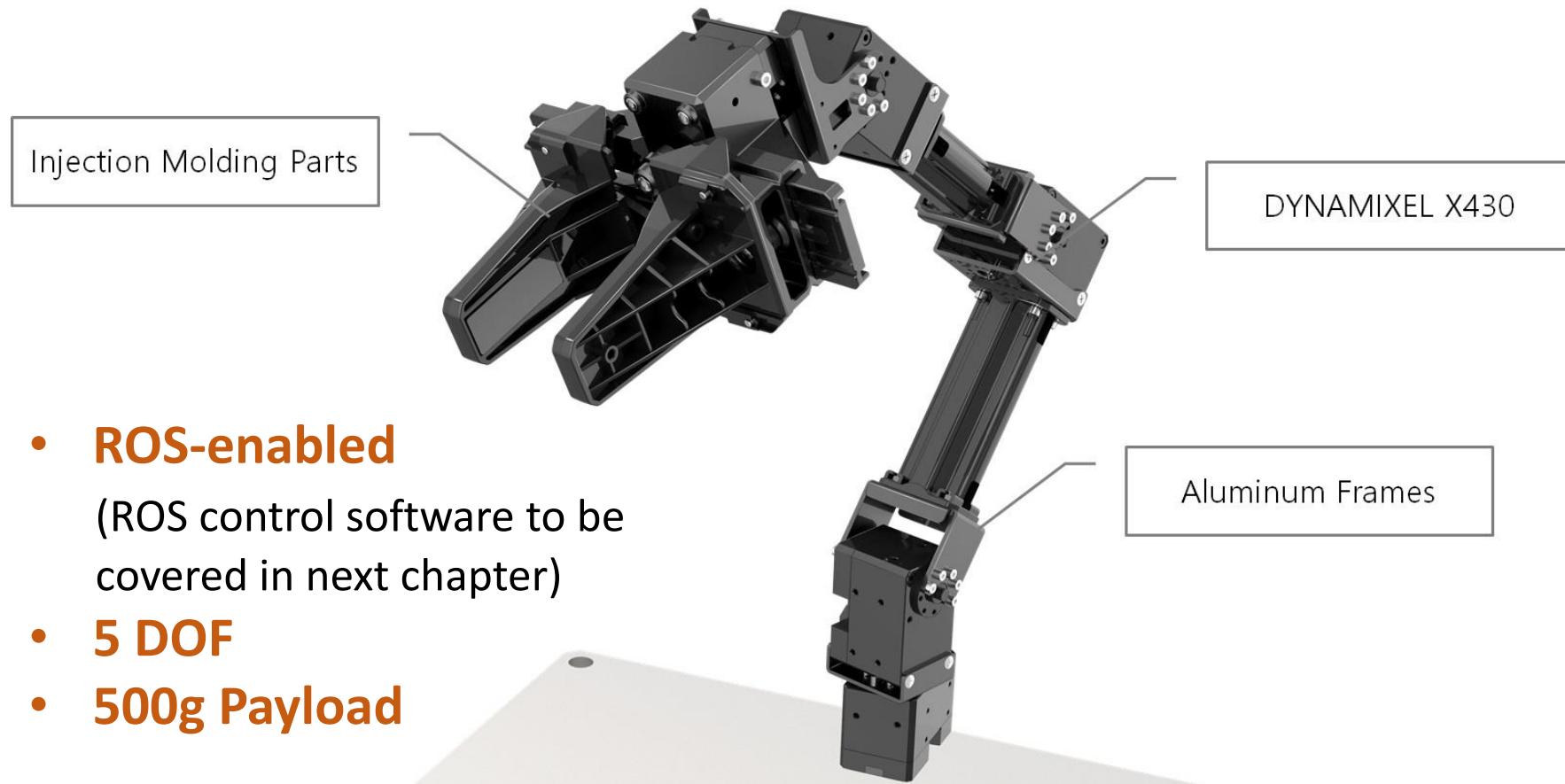
(will be practiced for this course)

Robotic Arm – OpenManipulator-X



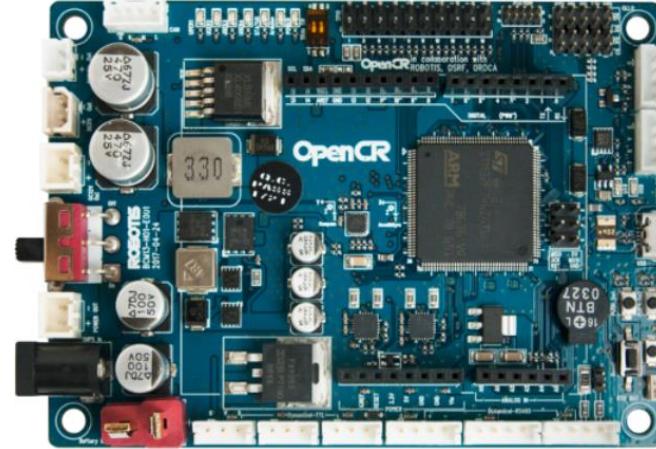
Source: <https://youtu.be/B2pnXtooKOg>

Robotic Arm – OpenManipulator-X

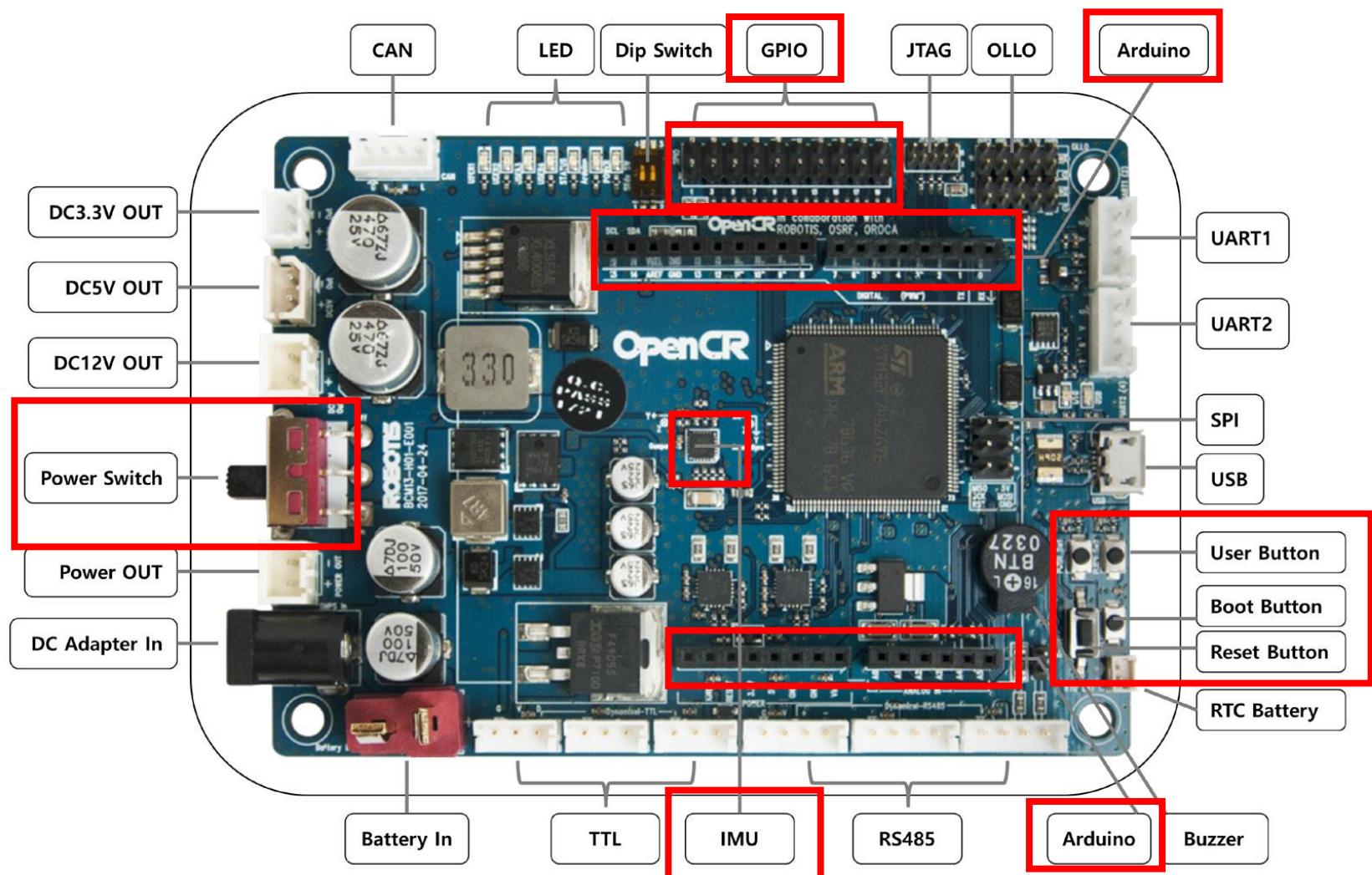


Introducing OpenCR board

- A type of **microcontroller**
- Developed for **ROS** embedded systems to provide completely open-source hardware and software
- Supports **Arduino IDE** software and **Arduino Uno boards** (attachable onto OpenCR board)
- **Hardware that reads inputs** (e.g. motor degrees, sensor readings) **and turn them into outputs** (e.g. activating motors)



OpenCR Interface Configuration



Chapter 3:

Introduction to ROS

Introducing ROS.org

What is ROS?

- An **open-source, meta-operating system for robots**
- Provides **services like** hardware abstraction, low-level device control, implementation of commonly-used functionality, message-passing between processes, and package management
- Also provides **tools and libraries for obtaining, building, writing, and running code across multiple computers**
- Unlike conventional operating systems, it can be **used for numerous combinations of hardware implementation**
- A robot software platform that **provides various development environments specialized for developing robot application programs**

ROS is a Meta-Operating System

What is a Meta-Operating System?

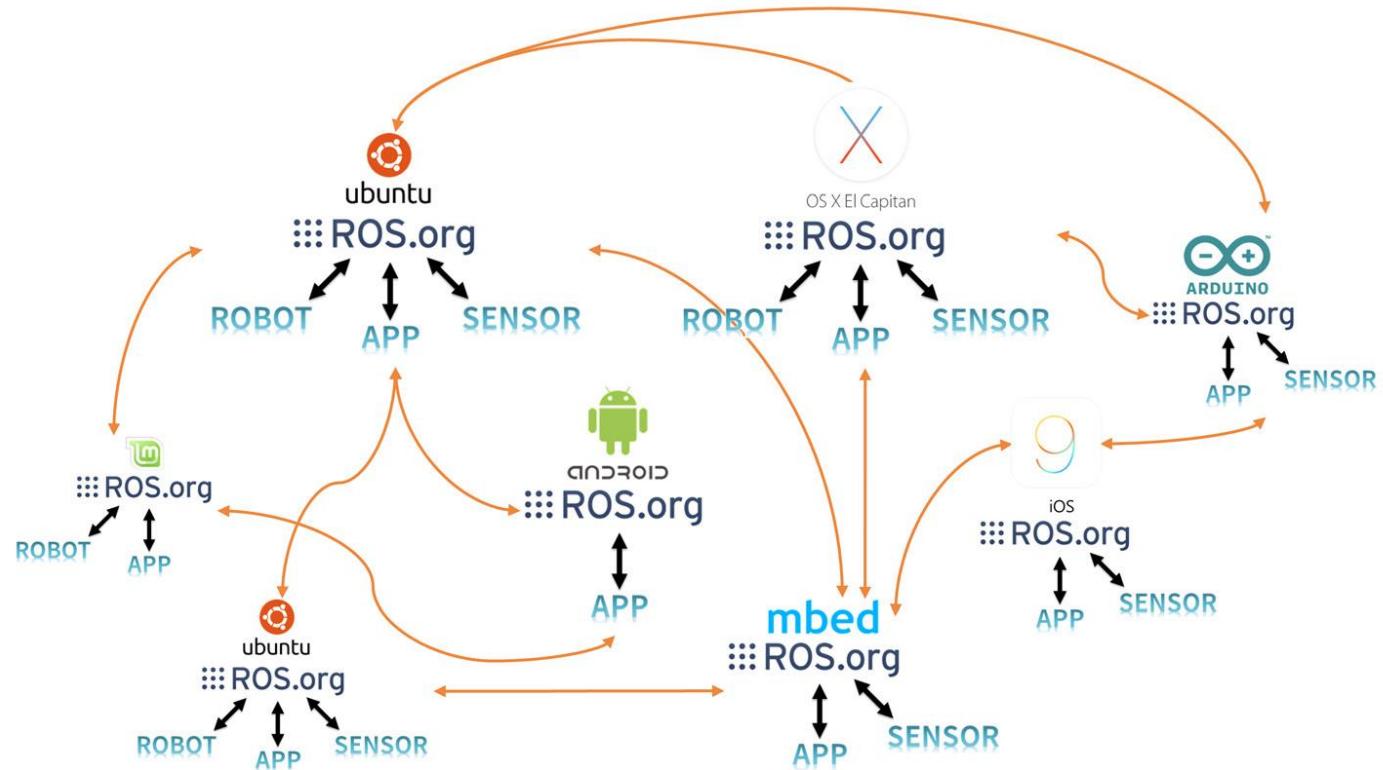
- Operating Systems (OS) for general purpose computers include Windows, Linux and Mac. For smartphones, there are Android, iOS, etc
- ROS is **NOT** a conventional OS; to be accurate, **ROS is a meta-operating system that runs on existing OS** (confusion with conventional OS)
- Formally defined as “***a system that performs processes such as scheduling, loading, monitoring and error handling by utilizing virtualization layer between applications and distributed computing resources***”

ROS is a Meta-Operating System



ROS is **a supporting system** for **controlling a robot and sensor with a hardware abstraction** and for **developing robot application based on existing conventional OSs**

ROS is a Meta-Operating System



ROS data communication is supported not only by one OS, but also by multiple operating systems, hardware, and programs, making it highly suitable for robot development where various hardware are combined

ROS Components



ROS Operation Test

To test if ROS is installed properly and works correctly (Let's Try!):

1. Open a new terminal window (*Ctrl + Alt + t*) and **enter \$ roscore**
2. **Run turtlesim_node** in the turtlesim package
3. **Run turtle_teleop_key** in the turtlesim package
4. **Run rqt_graph** in the rqt_graph package
5. **Close the node** (*Ctrl+c*)

*Installation of ROS will NOT be covered in this course; if you are interested, refer to workshop materials

Run `roscore`

```
File Edit View Search Terminal Help
pyo@pyo ~ $ roscore
... logging to /home/pyo/.ros/log/d257f510-60cc-11e7-b113-08d40c80c500/roslaunch
-pyo-7562.log
Checking log directory for disk usage. This may take awhile.
Press Ctrl-C to interrupt
Done checking log file disk usage. Usage is <1GB.

started roslaunch server http://localhost:38881/
ros_comm version 1.12.7

SUMMARY
-----
PARAMETERS
* /rosdistro: kinetic
* /rosversion: 1.12.7

NODES

auto-starting new master
process[master]: started with pid [7573]
ROS_MASTER_URI=http://localhost:11311/

setting /run_id to d257f510-60cc-11e7-b113-08d40c80c500
process[rosout-1]: started with pid [7586]
started core service [/rosout]
```

Screen showing `roscore` running

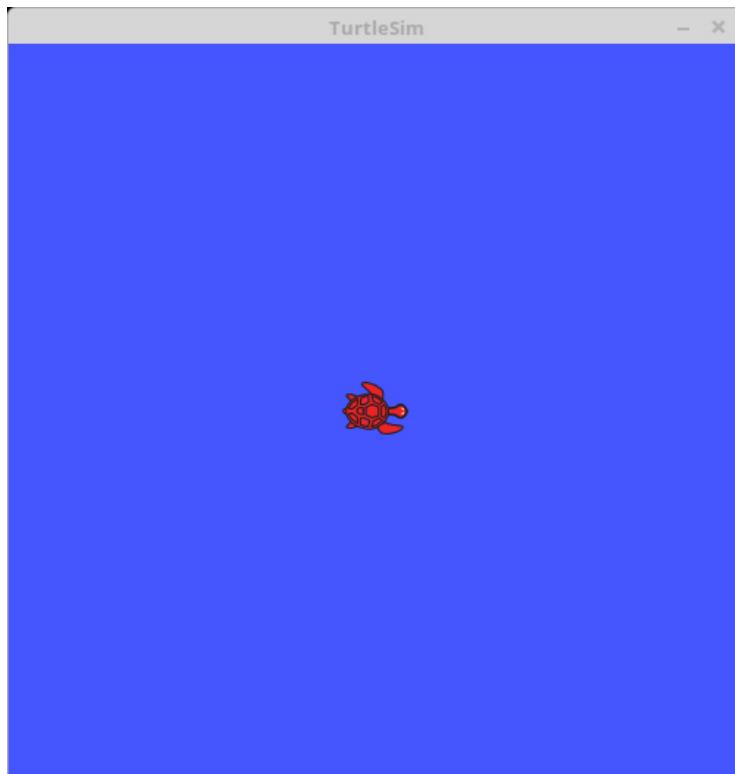
*`roscore` is the command that runs the ROS master (aka server)

Run turtlesim_node

Open a new terminal window and enter:

```
$ rosrun turtlesim  
turtlesim_node
```

A window will pop out with a turtle in the middle:



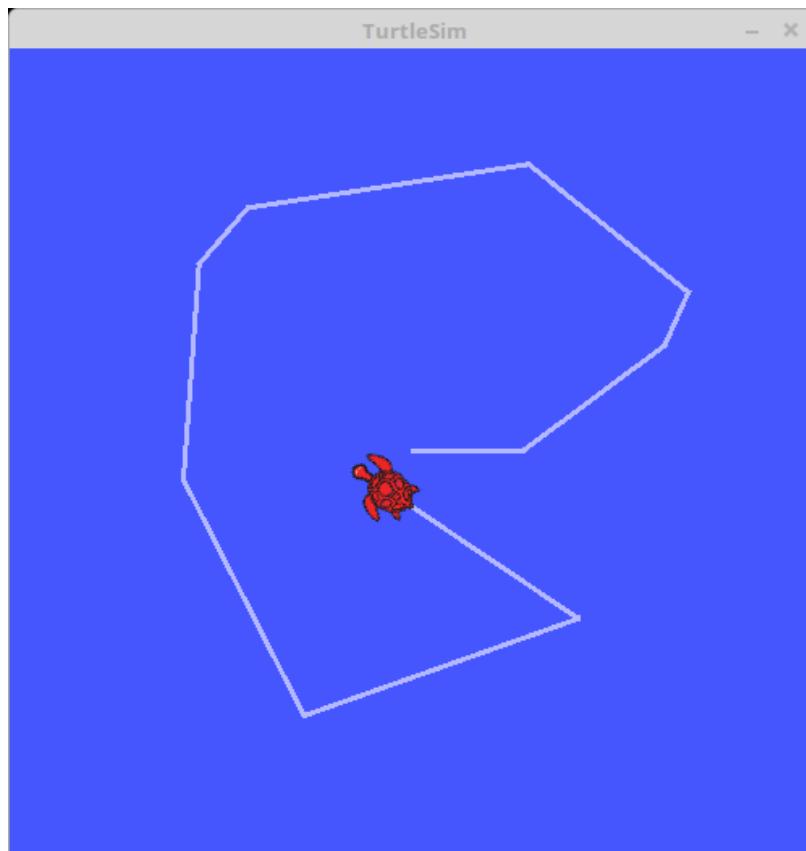
*rosrun is the basic execution command of ROS; used to run a single node in the package

Run turtle_teleop_key

Open a new terminal window
and enter:

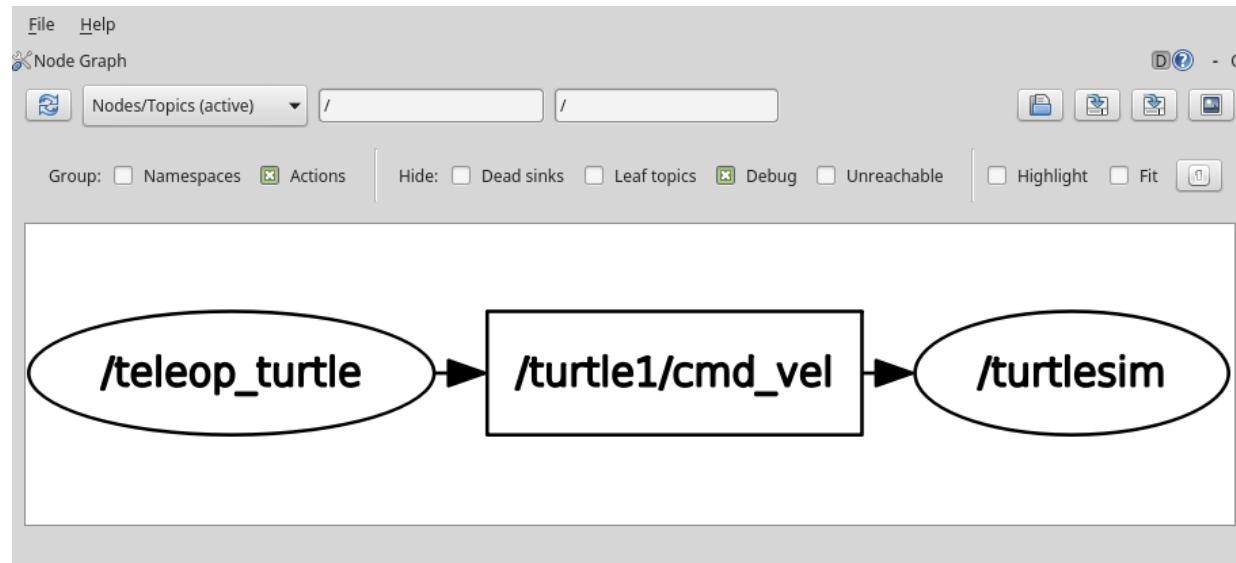
```
$ rosrun turtlesim  
turtle_teleop_key
```

You can use any of arrow keys on
the keyboard (\leftarrow , \rightarrow , \uparrow , \downarrow) to
move the turtle



Run rqt_graph

Open a new terminal window and enter: \$ rqt_graph



After done, at each terminal, enter Ctrl+c to close all the programs

- The rqt_graph node shows **information about the currently running nodes in a GUI form**;
- **Circle represents a node** (program) and **square represents a topic** (message communication)

Download & Install Robotics ROS Package

Steps:

1. Change to the source space directory of the catkin workspace:

```
$ cd ~/catkin_ws/src
```

2. Git Clone the Robotics package:

```
$ git clone https://github.com/nicholashojunhui/robotics.git
```

3. Build the packages in the catkin workspace:

```
$ cd ~/catkin_ws && catkin_make
```

4. Go to *catkin_ws/src/robotics/src* and make all python files executable

Creating a new ROS Package (Optional)

Steps:

1. Change to the source space directory of the catkin workspace:

```
$ cd ~/catkin_ws/src
```

2. Use the `catkin_create_pkg` script to create a new package called '***new_package***' which depends on `std_msgs`, `roscpp`, and `rospy`:

```
$ catkin_create_pkg new_package std_msgs rospy roscpp
```

3. Build the packages in the catkin workspace:

```
$ cd ~/catkin_ws
```

```
$ catkin_make
```

4. Add the workspace to your ROS environment by sourcing the generated setup file:

```
$ . ~/catkin_ws/devel/setup.bash
```

Definitions:

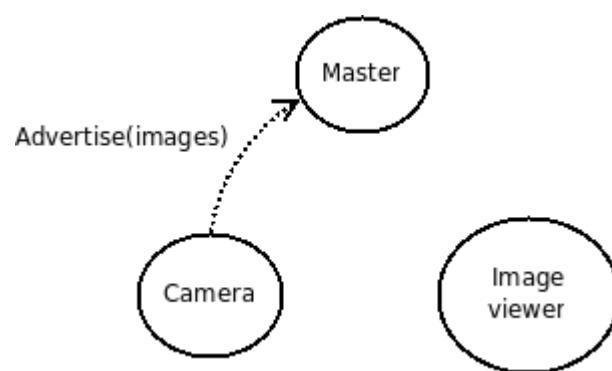
- A **ROS Topic** is a channel for communicating Messages among the Nodes
- A ROS Topic has a fixed Message type
- A Node **publishes** on a Topic to broadcast Messages
- A Node **subscribes** to a Topic to get Messages from other Nodes
- *Many-to-many* communication
 - One Node can publish/subscribe multiple Topics
 - One Topic can be published/subscribed by different Nodes
- **ROS Services** are another way that nodes can communicate with each other
- ROS Services allow nodes to send a request and receive a response

ROS Master

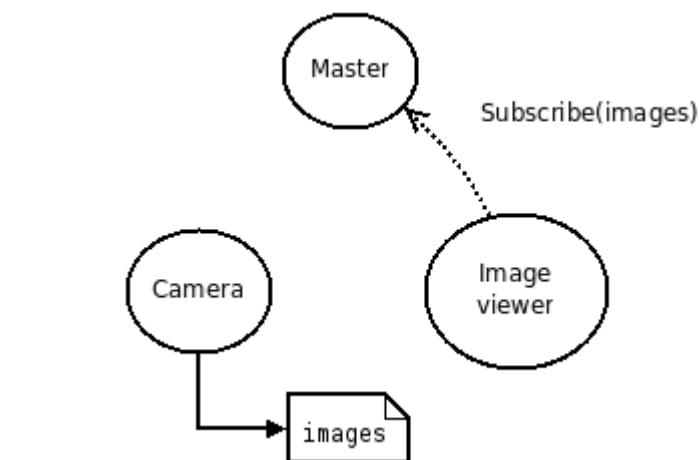
- The ROS Master **provides naming and registration services to the rest of the nodes** in the ROS system
- It **tracks publishers and subscribers to topics as well as services**
- Its role is to **enable individual ROS nodes to locate one another**
- Once these nodes have located each other via the ROS Master, they communicate with each other peer-to-peer
- Run using the **roscore command**, which loads the ROS Master

ROS Master (Example)

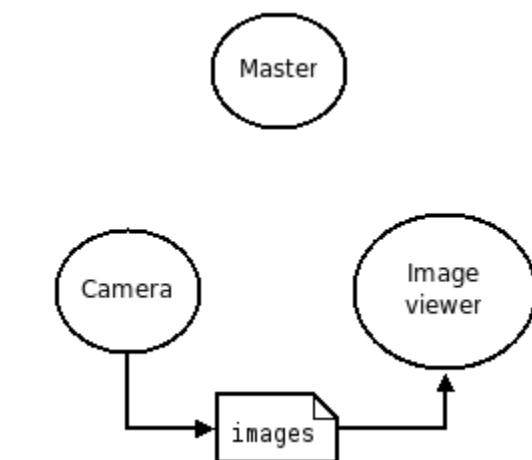
Let's say we have two Nodes: a Camera node and an Image_viewer node



The Camera will notify the master that it wants to publish images on the topic "images"

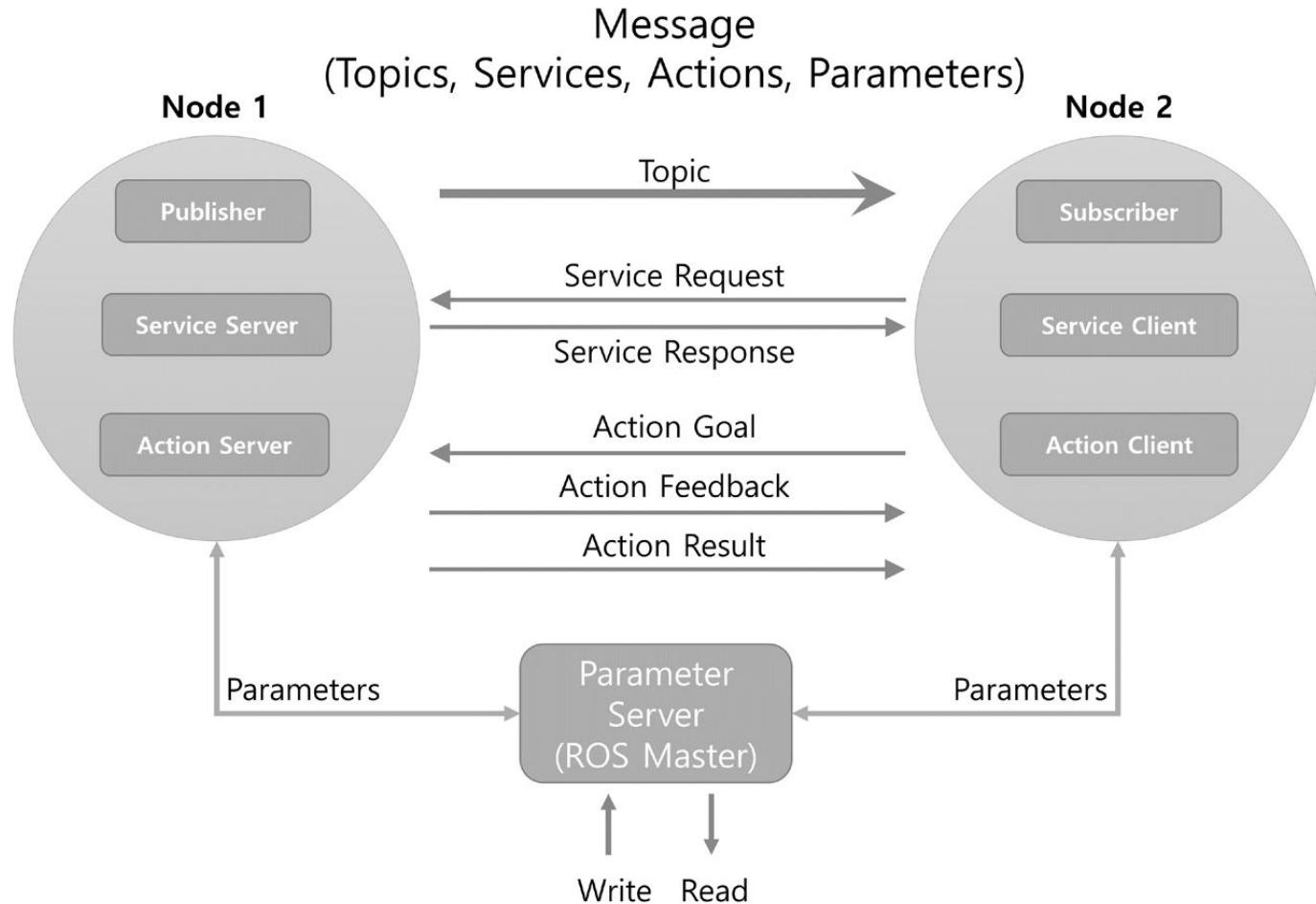


- The Camera will publish images to the "images" topic, but nobody is subscribing to that topic yet so no data is actually sent
- Same time, Image_viewer will subscribe to the topic "images" to see if there is any images there

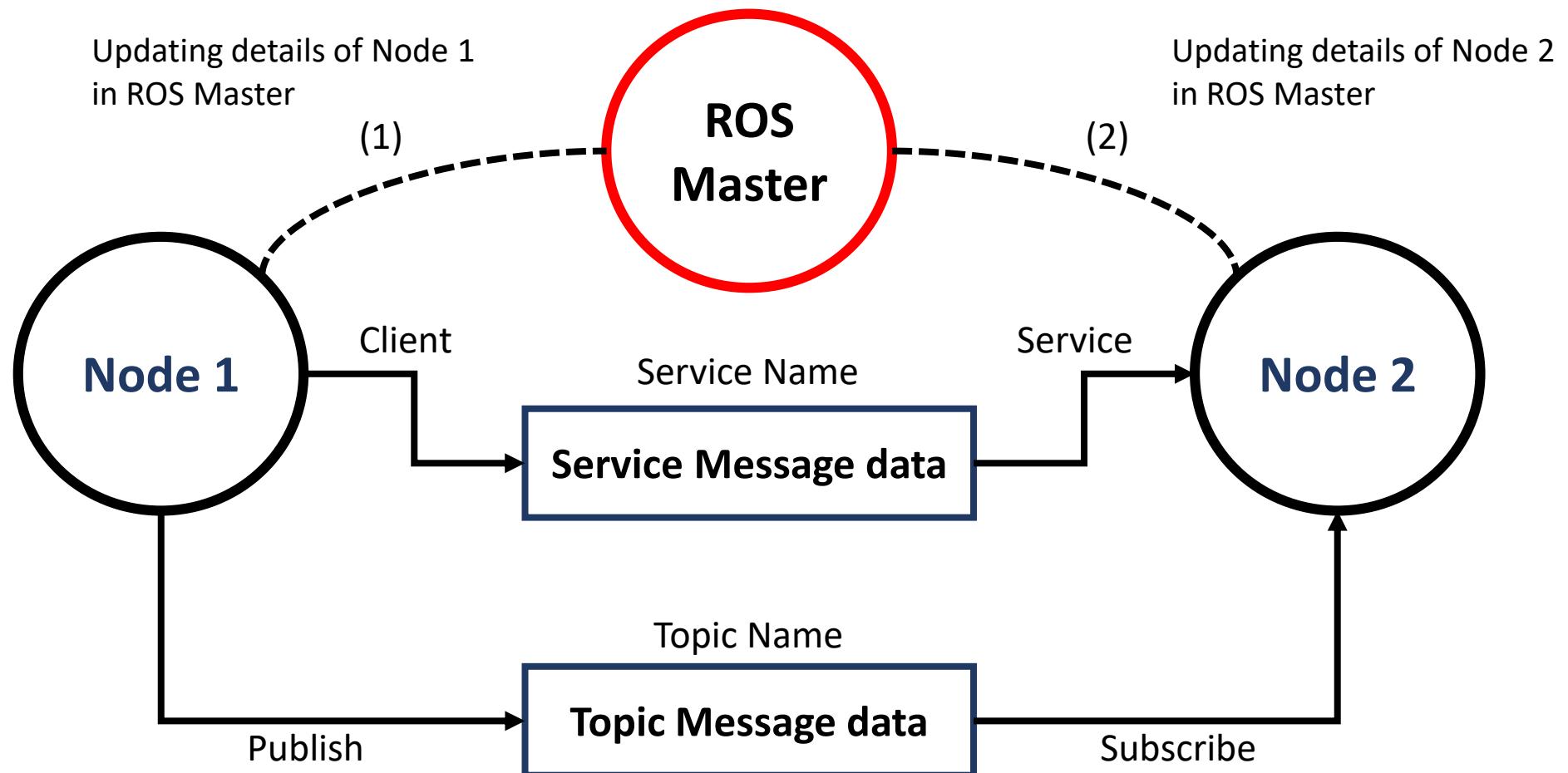


Once the topic "images" has both a publisher and a subscriber, the master node notifies Camera and Image_viewer about each others existence so that they can start transferring images to one another

ROS Communication Block Diagram:



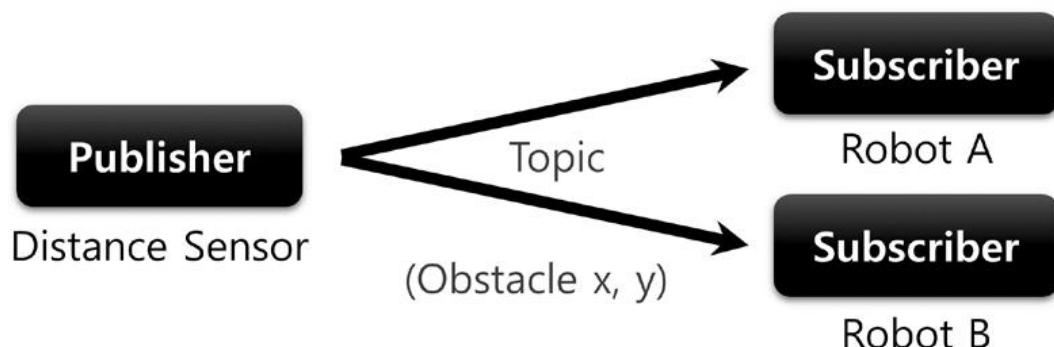
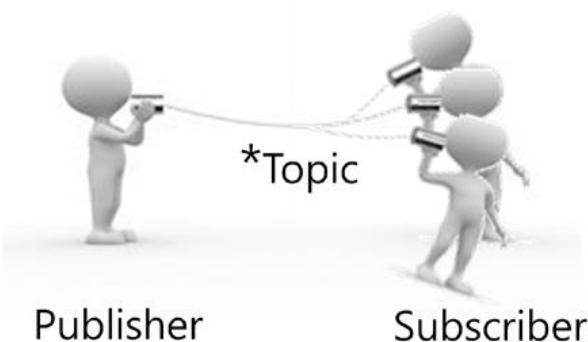
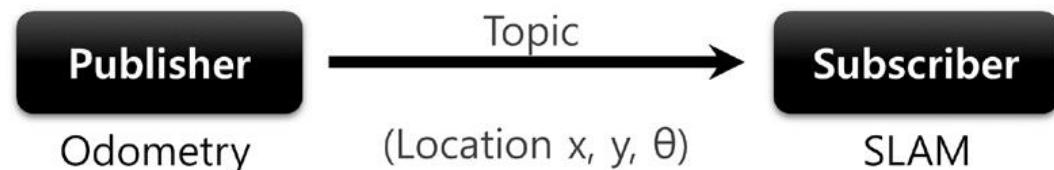
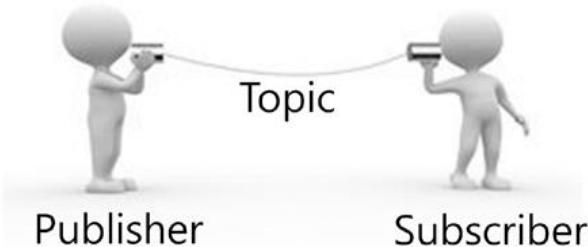
ROS Communication Block Diagram (simplified):



Comparison of Topic, Service and Action

Type	Features		Description
Topic	Asynchronous	Unidirectional	Used when exchanging data continuously
Service	Synchronous	Bi-directional	Used when request processing requests and responds current states
Action	Asynchronous	Bi-directional	Used when it is difficult to use the service due to long response times after the request or when an intermediate feedback value is needed

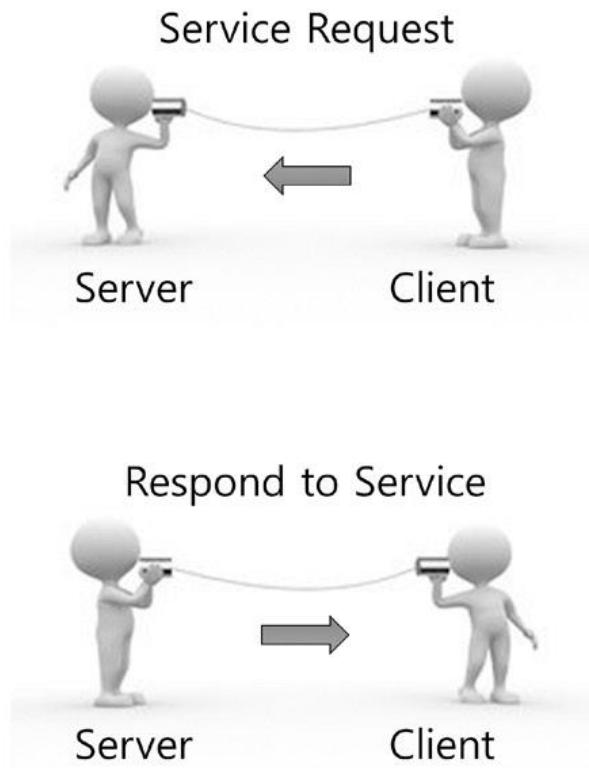
Topic Message Communication



*Topic not only allows 1:1 Publisher and Subscriber communication, but also supports 1:N, N:1 and N:N depending on the purpose.

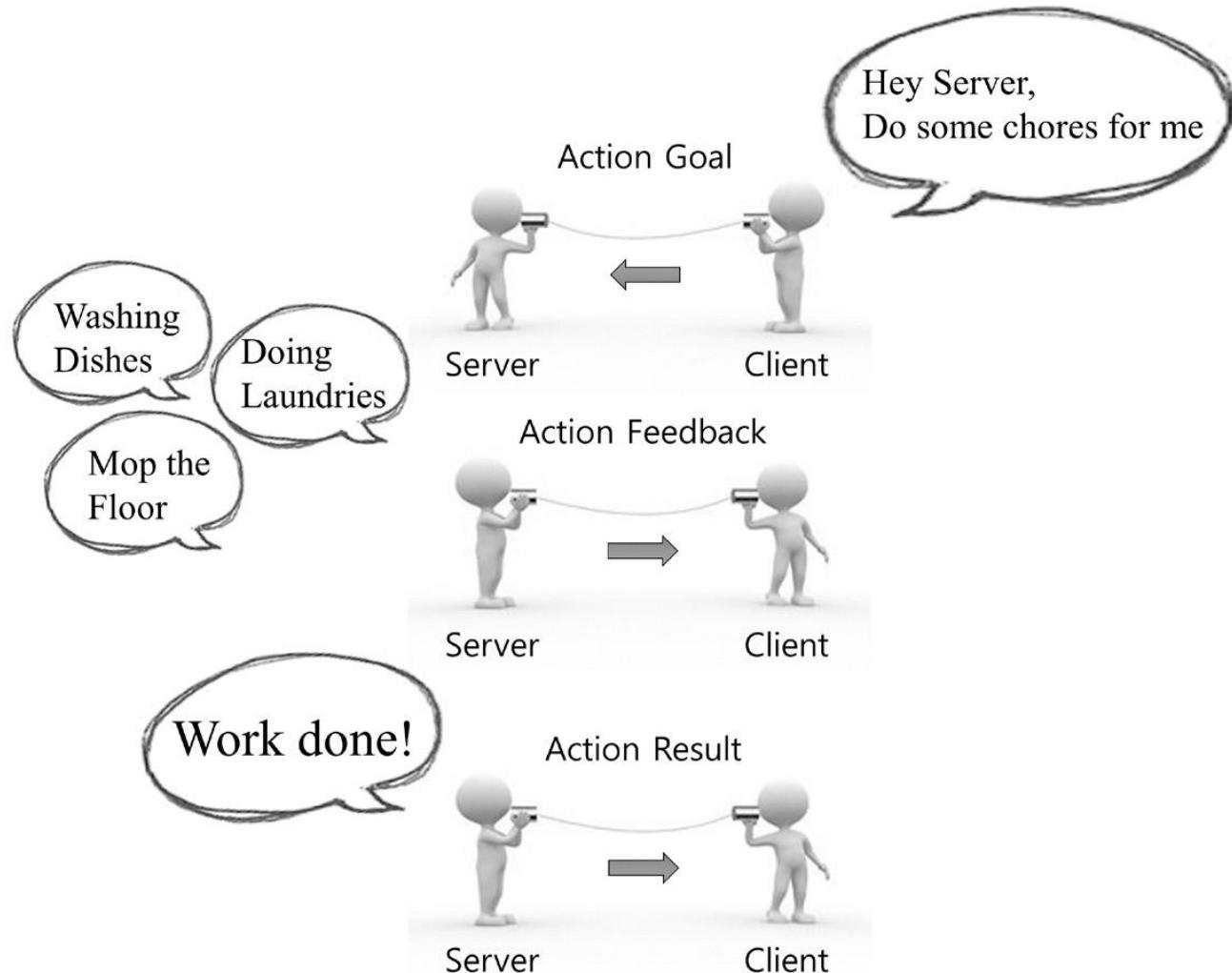
Service Message Communication

Let me see...
It's 12 O'clock!

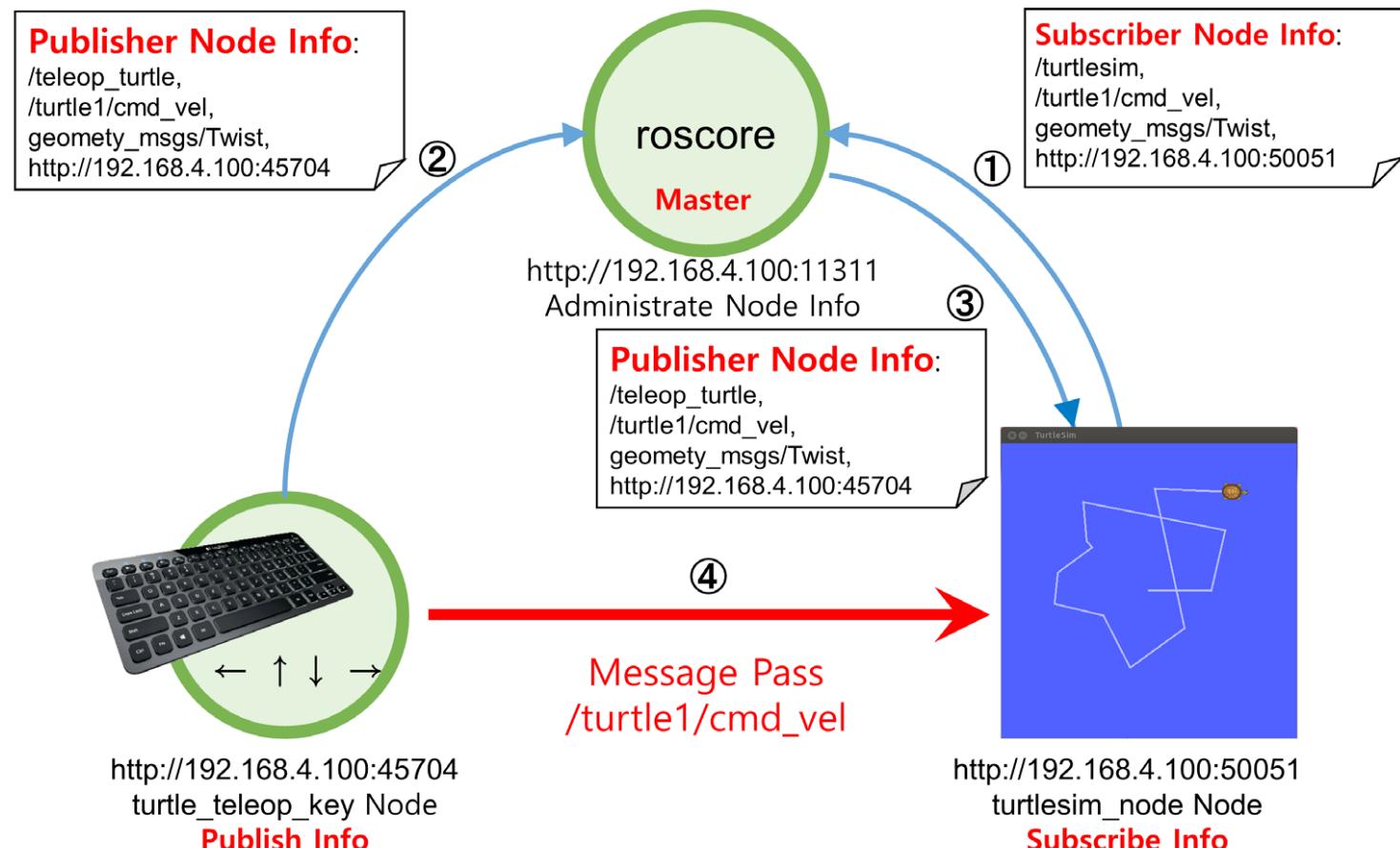


Hey Server,
What time is it now?

Action Message Communication



Example of Message Communication



Roslaunch vs Rosrun

- **Rosrun** is a command that runs only one node in the specified package

```
rosrun [PACKAGE_NAME] [NODE_NAME]
```

- **Roslaunch** is a command that executes more than one node in the specified package or sets execution options

```
roslaunch [PACKAGE_NAME] [launch_FILE_NAME]
```

ROS BASICS (General)

First, run roscore and the turtlesim_node

```
$ roscore
```

```
$ rosrun turtlesim turtlesim_node
```

We will open new terminal and try the following (one by one):

1. \$ rostopic list

2. \$ rostopic type /turtle1/cmd_vel

3. \$ rosmsg show geometry_msgs/Twist

ROS BASICS (General)

Next, open new terminal and try the following to move the turtlebot with the inputs:

```
$ rostopic pub /turtle1/cmd_vel geometry_msgs/Twist "linear:  
  x:1  
  y:0  
  z:0  
angular:  
  x:0  
  y:0  
  z:1.57"
```

***Note that you do not need to enter the complete command. Use the Tab key to autocomplete the command. Just type **rostopic pub /turtle1/cmd_vel**, and keep pressing the Tab key to autocomplete other fields. Don't forget to change the linear.x and angular.z values first before pressing the Enter key

ROS BASICS (Python)

Instead of using the above commands to move the turtlebot, we can write a Python code (i.e. `move_turtle.py`) to do the same movements; to run the Python code, follow the steps:

```
$ roscore
```

```
$ rosrun turtlesim turtlesim_node
```

```
$ rosrun robotics move_turtle.py 1.0 1.57
```

You will get the same output as the previous slide commands when you run this code. It creates a circle. You can change the input values to your liking

ROS BASICS (Python)

Instead of using only the input velocities to move the turtlebot, we can write a Python code (i.e. move_distance.py) based on stated position; to run the Python code, follow the steps:

```
$ roscore  
$ rosrun turtlesim turtlesim_node  
$ rosrun robotics move_distance.py 1.0 0.0 8.0
```

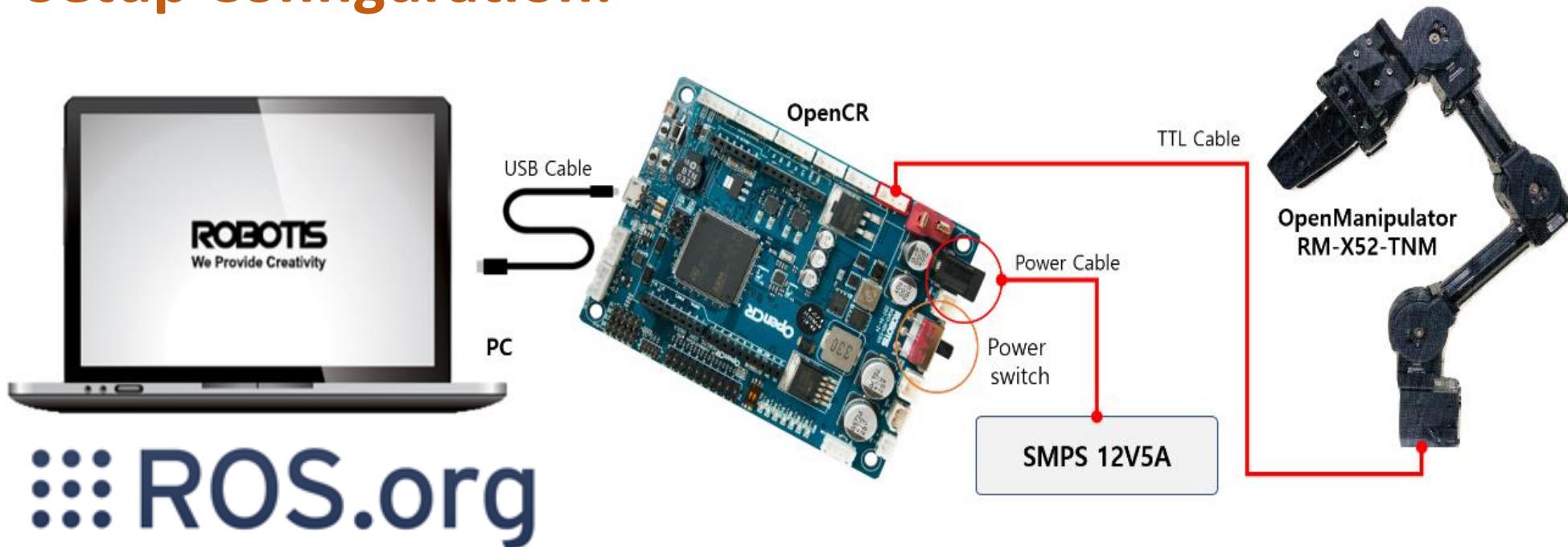
This code makes the turtle moves forward until $x = 8.0\text{m}$ at a velocity of 1m/s . You can change the input values to your liking. Note that the initial position of the turtle is $[x=5.54, y=5.54, \theta=0.0]$

Chapter 4:

Using ROS to Control OM

Using ROS as the Robot Controller

Setup Configuration:



 ROS.org

5 Steps to do before you can start using the OM Robotic Arm

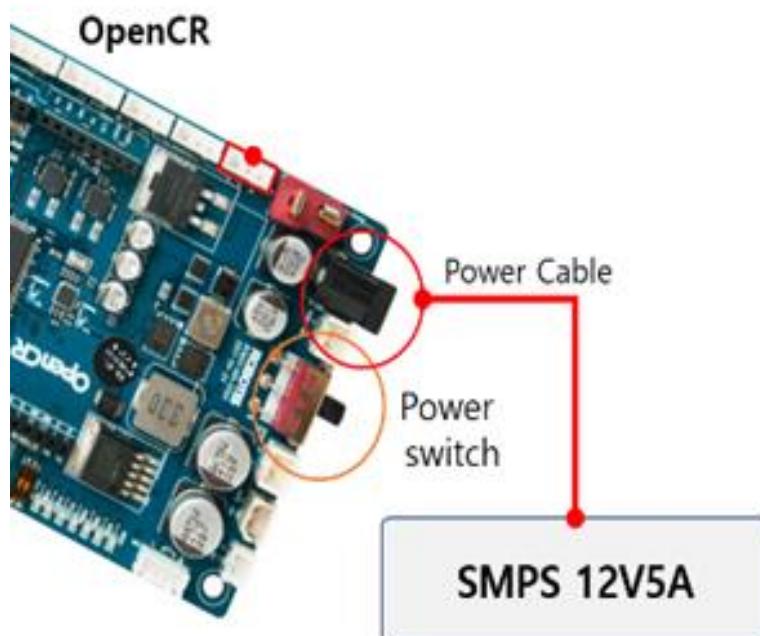
1. **Connect the board to your computer** using the **USB cable** (i.e. the USB extension cable)
2. **Connect the board and the power source** using the **power cable** (Do NOT switch on the power first)
3. **Open the Arduino IDE software and do the board setup** (only need to do this once)
4. **Launch the controller codes**
5. **You are ready to control the OM Robotic Arm using ROS software** (there are various methods to do so; we will go through 3 methods: manual, MoveIt! application, and python methods)

*Note that the motors and the board are already connected for you

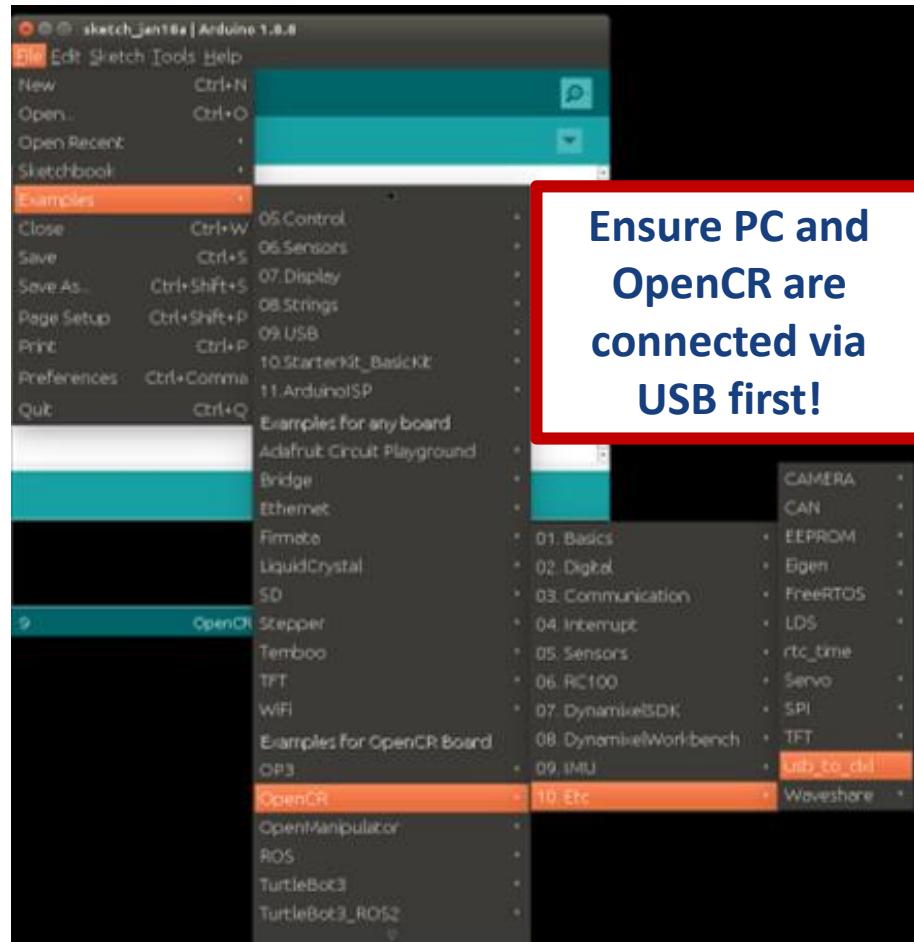
Step 1: Connect the board to your computer using the USB extension cable



Step 2: Connect the board and the power source using the power cable (Do NOT switch on the power first)

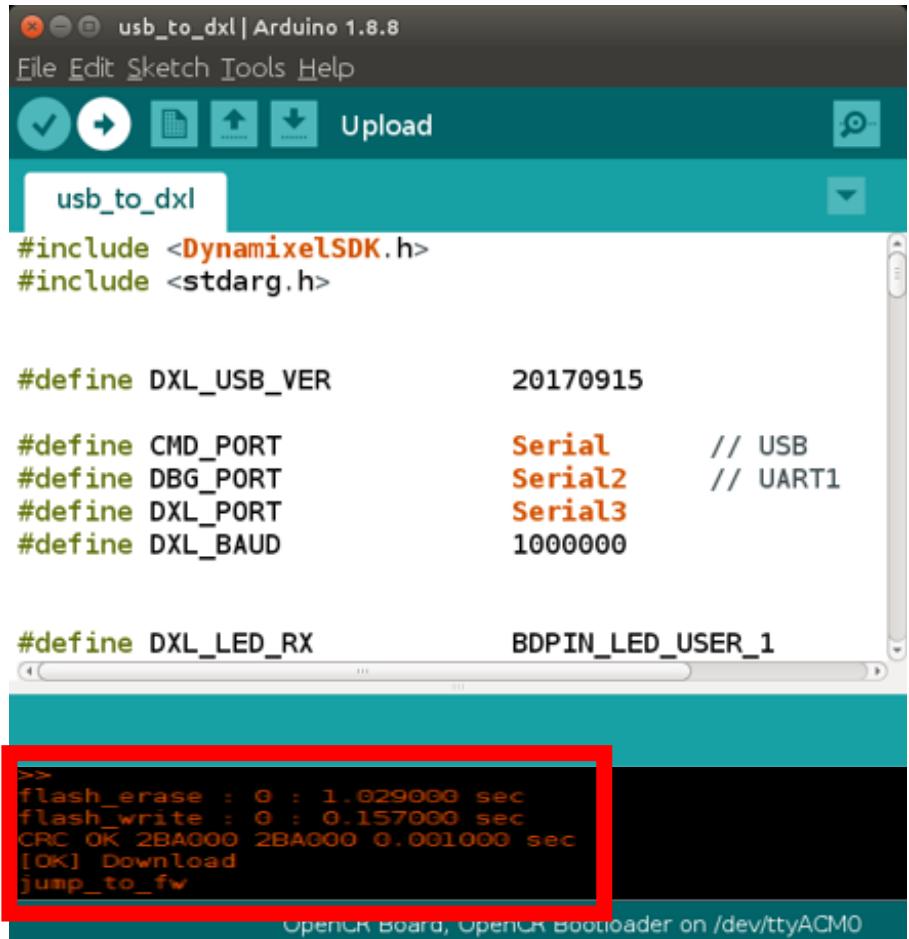


Step 3: OpenCR Setup (do it ONCE!)



1. Open Arduino IDE software in your PC
2. Go to Examples → OpenCR → 10.Etc → usb_to_dx1 to open the usb_to_dx1 example source code

Step 3: OpenCR Setup (do it ONCE!)



The screenshot shows the Arduino IDE interface with the sketch `usb_to_dxl` open. The code includes definitions for serial ports and a LED pin. The terminal window at the bottom shows the upload process and a command prompt.

```

usb_to_dxl | Arduino 1.8.8
File Edit Sketch Tools Help
Upload
usb_to_dxl
#include <DynamixelSDK.h>
#include <stdarg.h>

#define DXL_USB_VER      20170915
#define CMD_PORT         Serial // USB
#define DBG_PORT         Serial2 // UART1
#define DXL_PORT          Serial3
#define DXL_BAUD        1000000

#define DXL_LED_RX       BDPIN_LED_USER_1

>>>
flash_erase : 0 : 1.029000 sec
flash_write : 0 : 0.157000 sec
CRC OK 2BA000 2BA000 0.001000 sec
[OK] Download
jump_to_fw

```

OpenCR Board, OpenCR Bootloader on /dev/ttyACM0

3. Click Upload. If launched successfully, the terminal will appear as follows (left)

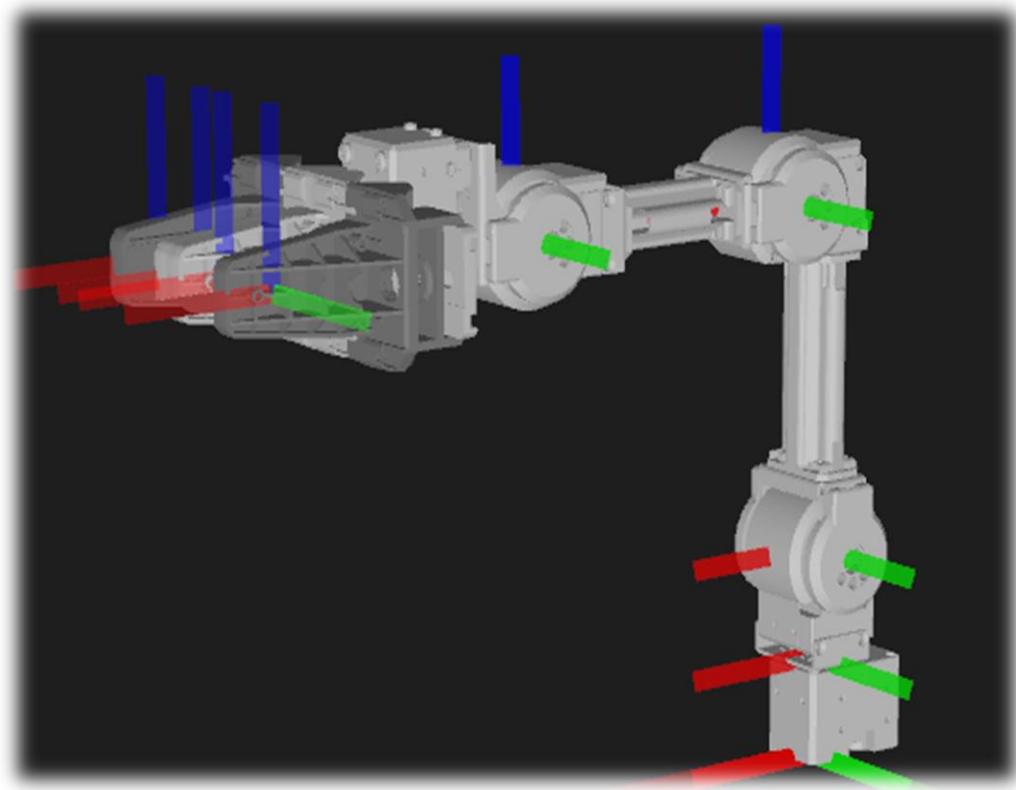
- `jump_to_fw` will appear at the end of the line

Step 4: Launch Controller using ROS

Important!!!

**Before you launch the controller codes,
manually lift the arm to
a “L” position first!!!**

**With the end effector
(i.e. the gripper) facing
the front
(refer to right image)**



Step 4: Launch Controller using ROS

Important!!!

Before you close the terminal with the launched controller codes OR before you switch off the power, manually support the arm first!!! And slowly put it down.

If not, the arm motors will be switch off, and it will fall and may injure someone or damage the robot/sensors

Step 4: Launch Controller using ROS

```

SUMMARY
=====

PARAMETERS
* /open_manipulator/control_period: 0.01
* /open_manipulator/moveit_sample_duration: 0.05
* /open_manipulator/planning_group_name: arm
* /open_manipulator/using_moveit: False
* /open_manipulator/using_platform: True
* /rosdistro: kinetic
* /rosversion: 1.12.14

NODES
/
  open_manipulator (open_manipulator_controller/open_manipulator_controller)

ROS_MASTER_URI=http://localhost:11311

process[open_manipulator-1]: started with pid [23452]
Joint Dynamixel ID : 11, Model Name : XM430-W350
Joint Dynamixel ID : 12, Model Name : XM430-W350
Joint Dynamixel ID : 13, Model Name : XM430-W350
Joint Dynamixel ID : 14, Model Name : XM430-W350
Gripper Dynamixel ID : 15, Model Name :XM430-W350
[ INFO] [1544509070.096942788]: Succeeded to init /open_manipulator

```

*****Ensure the ARM is switched on first**

Type (in New Terminal):

- \$ roscore
- \$ roslaunch open_manipulator_controller open_manipulator_controller.launch
- If launched successfully, the terminal will appear as follows (left)
- You are ready to control your robotic arm

Step 4: Launch Controller using ROS

Note that if you can't launch your controller successfully, double check if the USB port in the launch file is defined correctly

- From Home, search and open `open_manipulator_controller.launch`
- Ensure that the following line is as such: `<arg name="dynamixel_usb_port" default="/dev/ttyACM0"/>`

ROS BASICS (for OM)

We will open new terminal and try the following (one by one):

1. \$ rostopic list
2. \$ rosservice list
3. \$ rostopic echo /joint_states -n1
4. \$ rqt (will be covered in WS2)

Step 5: Control OM using ROS Software

(a) Manual Control

```
-----
Control Your OpenMANIPULATOR-X!
-----

w : increase x axis in task space
s : decrease x axis in task space
a : increase y axis in task space
d : decrease y axis in task space
z : increase z axis in task space
x : decrease z axis in task space

y : increase joint 1 angle
h : decrease joint 1 angle
u : increase joint 2 angle
j : decrease joint 2 angle
i : increase joint 3 angle
k : decrease joint 3 angle
o : increase joint 4 angle
l : decrease joint 4 angle

g : gripper open
f : gripper close
```

*****Ensure the ARM is switched on and the Controller is activated first**

Type (in New Terminal):

- \$ roslaunch open_manipulator_teleop open_manipulator_teleop_keyboard.launch
- If the node is successfully launched, the following instruction will appear in the terminal window (left)
- Use your keyboard keys to control the arm; the arm will respond accordingly
- Close terminal when done

Step 5: Control OM using ROS Software

(b) Control via Python (rospy)

Important!!!

Before you close the terminal with the launched controller codes OR before you switch off the power, manually support the arm first!!! And slowly put it down.

If not, the arm motors will be switch off, and it will fall and may injure someone or damage the robot/sensors

Step 5: Control OM using ROS Software

(b) Control via Python (rospy)

Published Topic List : A list of topics that the open_manipulator_controller publishes.

- `/open_manipulator/states`
- `/open_manipulator/joint_states`
- `/open_manipulator/gripper/kinematics_pose`
- `/open_manipulator/*joint_name*_position/command`
- `/open_manipulator/rviz/moveit/update_start_state`

NOTE: These topics are messages for checking the status of the robot regardless of the robot's motion.

`/open_manipulator/joint_states` (`sensor_msgs/JointState`) is a message indicating the states of joints of OpenMANIPULATOR-X. “**name**” indicates joint component names. “**effort**” shows currents of the joint DYNAMIXEL. “**position**” and “**velocity**” indicates angles and angular velocities of joints.

`/open_manipulator/gripper/kinematics_pose` (`open_manipulator_msgs/KinematicsPose`) is a message indicating pose (position and orientation) in **task space**. “**position**” indicates the x, y and z values of the center of the end-effector (tool). “**Orientation**” indicates the direction of the end-effector (tool) as quaternion.

`/open_manipulator/states` (`open_manipulator_msgs/OpenManipulatorState`) is a message indicating the status of OpenMANIPULATOR. “**open_manipulator_actuator_state**” indicates whether actuators (DYNAMIXEL) are enabled (“ACTUATOR_ENABLE”) or disabled (“ACTUATOR_DISABLE”). “**open_manipulator_moving_state**” indicates whether OpenMANIPULATOR-X is moving along the trajectory (“IS_MOVING”) or stopped (“STOPPED”).

`/open_manipulator/*joint_name*_position/command` (`std_msgs/Float64`) are the messages to publish goal position of each joint to gazebo simulation node. “***joint_name***” shows the name of each joint. The messages will only be published if you run the controller package with the `use_platform` parameter set to `false`.

`/rviz/moveit/update_start_state` (`std_msgs/Empty`) is a message to update start state of moveit! trajectory. This message will only be published if you run the controller package with the `use_moveit` parameter set to `true`.

Step 5: Control OM using ROS Software

(b) Control via Python (rospy)

NOTE: These services are messages to operate OpenMANIPULATOR-X or to change the status of DYNAMIXEL of OpenMANIPULATOR.

Service Server List : A list of service servers that open_manipulator_controller has.

- `/open_manipulator/goal_joint_space_path` ([open_manipulator_msgs/SetJointPosition](#))

The user can use this service to create a trajectory in the **joint space**. The user inputs the angle of the target joint and the total time of the trajectory.

- `/open_manipulator/goal_joint_space_path_to_kinematics_pose` ([open_manipulator_msgs/SetKinematicsPose](#))

The user can use this service to create a trajectory in the **joint space**. The user inputs the kinematics pose of the OpenMANIPULATOR-X end-effector(tool) in the **task space** and the total time of the trajectory.

- `/open_manipulator/goal_joint_space_path_to_kinematics_position` ([open_manipulator_msgs/SetKinematicsPose](#))

The user can use this service to create a trajectory in the **joint space**. The user inputs the kinematics pose(position only) of the OpenMANIPULATOR-X end-effector(tool) in the **task space** and the total time of the trajectory.

- `/open_manipulator/goal_joint_space_path_to_kinematics_orientation` ([open_manipulator_msgs/SetKinematicsPose](#))

The user can use this service to create a trajectory in the **joint space**. The user inputs the kinematics pose(orientation only) of the OpenMANIPULATOR-X end-effector(tool) in the **task space** and the total time of the trajectory.

- `/open_manipulator/goal_task_space_path` ([open_manipulator_msgs/SetKinematicsPose](#))

The user can use this service to create a trajectory in the **task space**. The user inputs the kinematics pose of the OpenMANIPULATOR-X end-effector(tool) in the **task space** and the total time of the trajectory.

Step 5: Control OM using ROS Software

(b) Control via Python (rospy)

NOTE: These services are messages to operate OpenMANIPULATOR-X or to change the status of DYNAMIXEL of OpenMANIPULATOR.

Service Server List : A list of service servers that `open_manipulator_controller` has.

- `/open_manipulator/goal_task_space_path_position_only` (`open_manipulator_msgs/SetKinematicsPose`)
The user can use this service to create a trajectory in the `task space`. The user inputs the kinematics pose(position only) of the OpenMANIPULATOR-X end-effector(tool) in the `task space` and the total time of the trajectory.
- `/open_manipulator/goal_task_space_path_orientation_only` (`open_manipulator_msgs/SetKinematicsPose`)
The user can use this service to create a trajectory in the `task space`. The user inputs the kinematics pose(orientation only) of the OpenMANIPULATOR-X end-effector(tool) in the `task space` and the total time of the trajectory.
- `/open_manipulator/goal_joint_space_path_from_present` (`open_manipulator_msgs/SetJointPosition`)
The user can use this service to create a trajectory from present joint angle in the `joint space`. The user inputs the angle of the target joint to be changed and the total time of the trajectory.
- `/open_manipulator/goal_task_space_path_from_present` (`open_manipulator_msgs/SetKinematicsPose`)
The user can use this service to create a trajectory from present kinematics pose in the task space. The user inputs the kinematics pose to be changed of the OpenMANIPULATOR-X end-effector(tool) in the `task space` and the total time of the trajectory.
- `/open_manipulator/goal_task_space_path_from_present_position_only` (`open_manipulator_msgs/SetKinematicsPose`)
The user can use this service to create a trajectory from present kinematics pose in the `task space`. The user inputs the kinematics pose(position only) of the OpenMANIPULATOR-X end-effector(tool) in the `task space` and the total time of the trajectory.
- `/open_manipulator/goal_task_space_path_from_present_orientation_only` (`open_manipulator_msgs/SetKinematicsPose`)
The user can use this service to create a trajectory from present kinematics pose in the `task space`. The user inputs the kinematics pose(orientation only) of the OpenMANIPULATOR-X end-effector(tool) in the `task space` and the total time of the trajectory.
- `/open_manipulator/goal_tool_control` (`open_manipulator_msgs/SetJointPosition`)
The user can use this service to move the tool of OpenMANIPULATOR.
- `/open_manipulator/set_actuator_state` (`open_manipulator_msgs/SetActuatorState`)
The user can use this service to control the state of actuators.
If the user set true at `set_actuator_state` valuable, the actuator will be enabled.
If the user set false at `set_actuator_state` valuable, the actuator will be disabled.
- `/open_manipulator/goal_drawing_trajectory` (`open_manipulator_msgs/SetDrawingTrajectory`)
The user can use this service to create a drawing trajectory. The user can create the circle, the rhombus, the heart, and the straight line trajectory.

Step 5: Control OM using ROS Software

(b) Control via Python (rospy)

- **Ensure the ARM is switched on and the Controller is activated first**
- For this exercise, we will be using the python file: `control_om.py`
- First ensure your python files are in the *robotics* package folder in the *src* folder; you may create a folder named “*scripts*” to put all python files in it
- Open terminal and type:

```
$ rosrun robotics control_om.py
```

- The OM will move to a point determined by the joint angles. To alter these joint angles, open the python file, find the following line and change the angles in it; these angles are in radians:

```
joint_position.position = [-0.5, 0, 0.5, -0.5]
```

- To alter the gripper angles, alter the following line (-0.01 for fully close and 0.01 for fully open):

```
gripper_position.position = [0.01]
```

Step 5: Control OM using ROS Software

(b) Control via Python (rospy)

Note that if you can't execute the python file, you have to give execution permissions to it by typing (change directory first):

- \$ chmod +x name_of_the_file.py

Alternatively, a faster way to do this is to follow the steps below:

1. Select all your python files and Right Click
2. Click “Properties” and go to “Permissions” tab
3. Click the box beside “Allow executing file as program”; this box should have a tick inside

Step 5: Control OM using ROS Software

(b) Control via Python (rospy)

control_om.py

```

#!/usr/bin/env python
# works for actual OM ONLY!
# does not work for actual OM_with_TB3

import rospy
from open_manipulator_msgs.msg import JointPosition      #import the python library for ROS
from open_manipulator_msgs.srv import SetJointPosition    #import JointPosition message from the open_manipulator
from sensor_msgs.msg import JointState
import math
import time

def callback(msg):
    print msg.name
    print msg.position

def talker():
    rospy.init_node('OM_publisher') #Initiate a Node called 'OM_publisher'
    set_joint_position = rospy.ServiceProxy('/open_manipulator/goal_joint_space_path', SetJointPosition)
    set_gripper_position = rospy.ServiceProxy('/open_manipulator/goal_tool_control', SetJointPosition)

    while not rospy.is_shutdown():
        joint_position = JointPosition()
        joint_position.joint_name = ['joint1','joint2','joint3','joint4']
        joint_position.position = [-0.5, 0, 0.5, -0.5]          # in radians
        resp1 = set_joint_position('planning_group',joint_position, 3)
        gripper_position = JointPosition()
        gripper_position.joint_name = ['gripper']
        gripper_position.position = [0.01]      # -0.01 for fully close and 0.01 for fully open
        resp2 = set_gripper_position('planning_group',gripper_position, 3)

        sub_joint_state = rospy.Subscriber('/open_manipulator/joint_states', JointState, callback)

if __name__ == '__main__':
    try:
        talker()
    except rospy.ROSInterruptException:
        pass

```

Note if you can't execute the python file, you have to give execution permissions to it by typing:

\$ chmod +x name_of_the_file.py

Service Server

```

'/open_manipulator/goal_joint_space_path', SetJointPosition)
'/open_manipulator/goal_tool_control', SetJointPosition)

set_joint_position = rospy.ServiceProxy('/open_manipulator/goal_joint_space_path', SetJointPosition)
set_gripper_position = rospy.ServiceProxy('/open_manipulator/goal_tool_control', SetJointPosition)

resp1 = set_joint_position('planning_group',joint_position, 3)
resp2 = set_gripper_position('planning_group',gripper_position, 3)

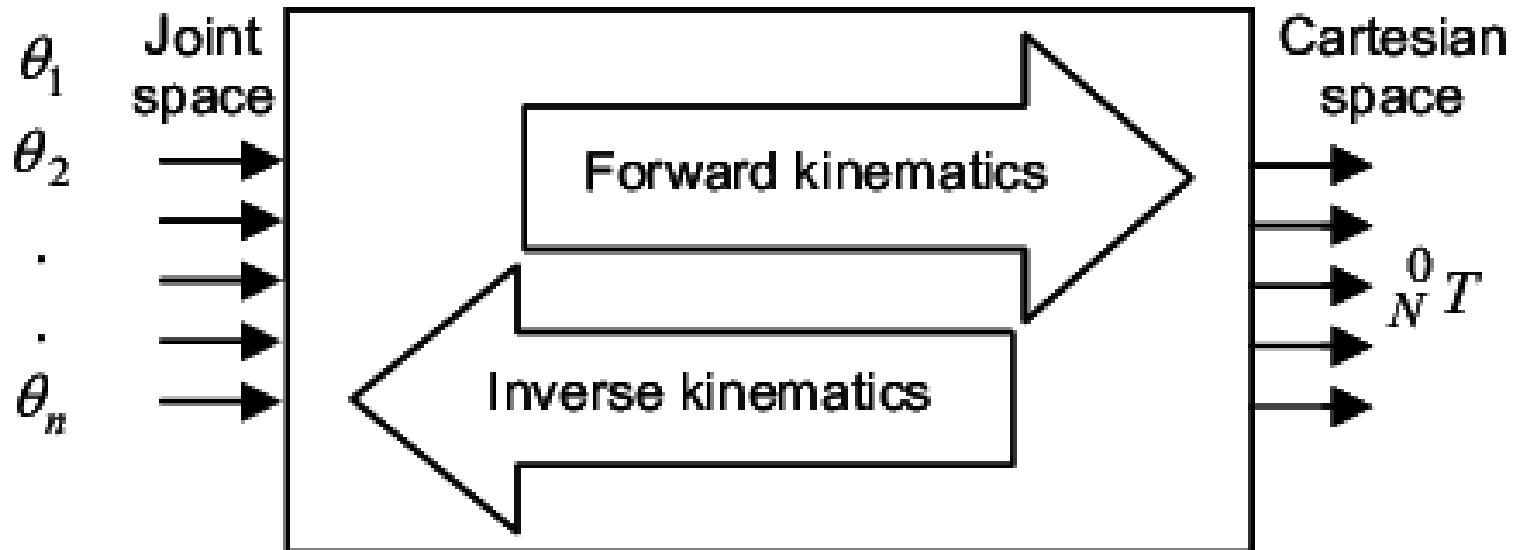
sub_joint_state = rospy.Subscriber('/open_manipulator/joint_states', JointState, callback)

```

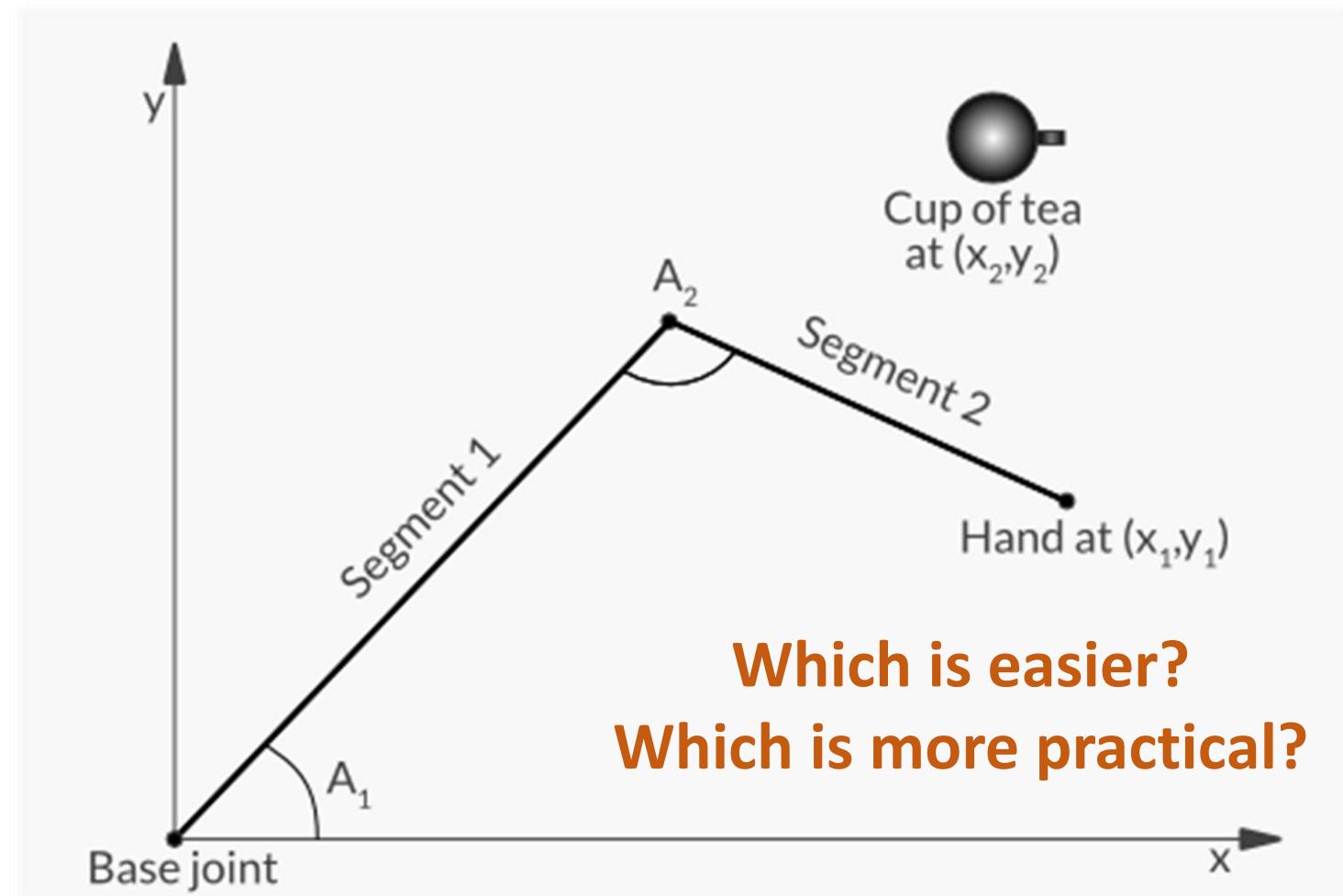
Subscriber

Chapter 5: Basic micro-management of the robotic arm

Difference between Forward & Inverse Kinematics



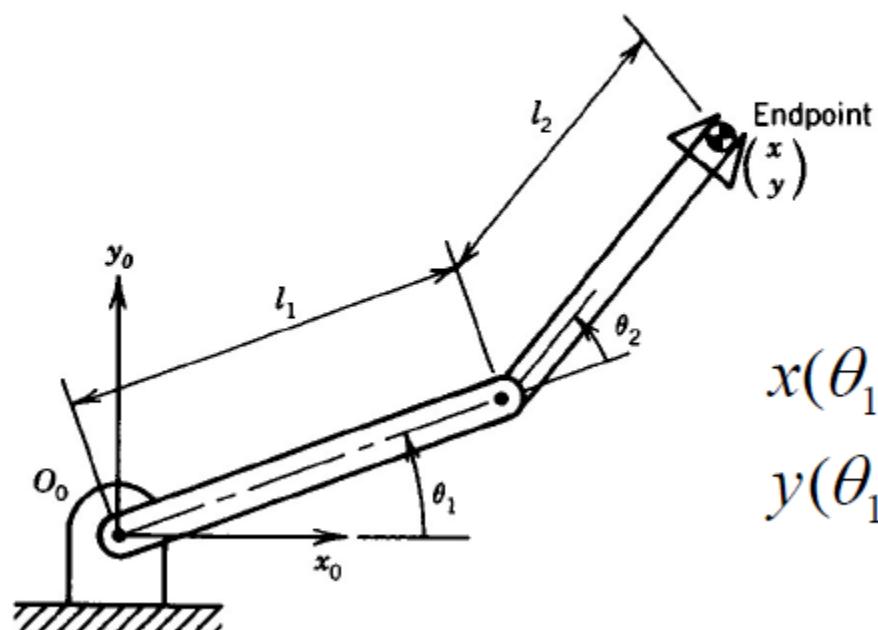
Difference between Forward & Inverse Kinematics



Finding the Motor Angles using IK

Method 1: Algebraic

Consider the following 2 dof planar manipulator:



**What are the limitations
with this method?**

$$x(\theta_1, \theta_2) = l_1 \cos \theta_1 + l_2 \cos(\theta_1 + \theta_2)$$

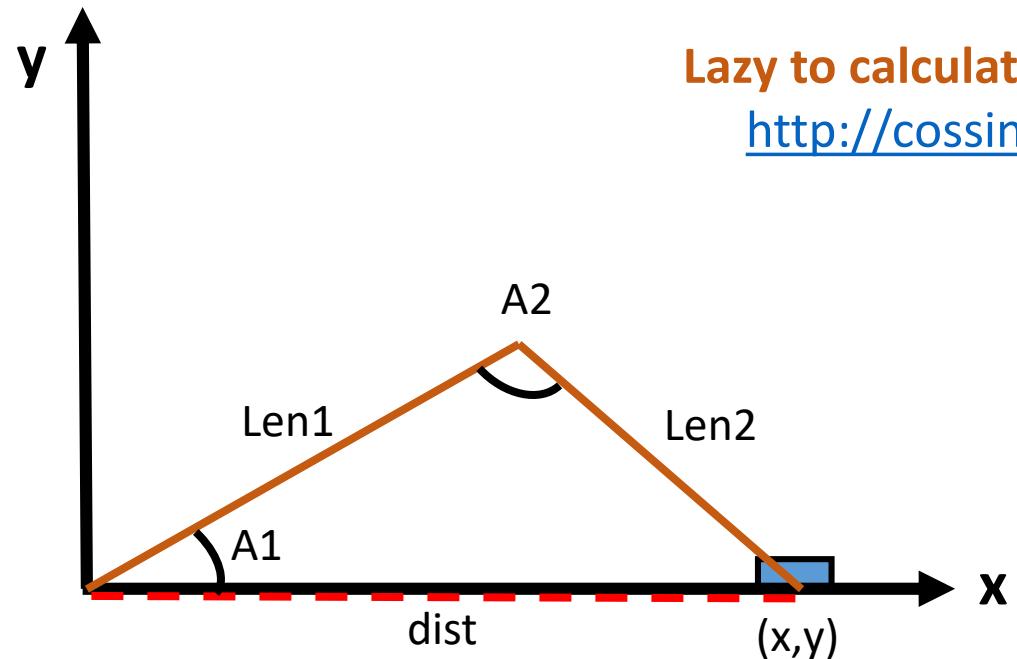
$$y(\theta_1, \theta_2) = l_1 \sin \theta_1 + l_2 \sin(\theta_1 + \theta_2)$$

Basic micro-management of the robotic arm

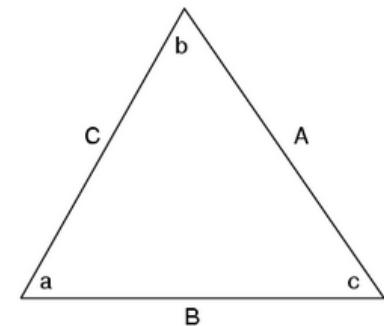
- 1. Determine the reference angles required**
- 2. Plan the various stages & determine motor angles at each stage**
- 3. Configure and execute codes in the control software**

Basic micro-management of the robotic arm

1. Determine the reference angles (i.e. A1 and A2) using inverse kinematics – Method 2: Geometric



Lazy to calculate the angles?
<http://cossin calc.com/>



The Law of Sines (for any triangle)

$$\frac{\sin a}{A} = \frac{\sin b}{B} = \frac{\sin c}{C}$$

The Law of Cosines (for any triangle)

$$A^2 = B^2 + C^2 - 2BC(\cos a)$$

$$B^2 = A^2 + C^2 - 2AC(\cos b)$$

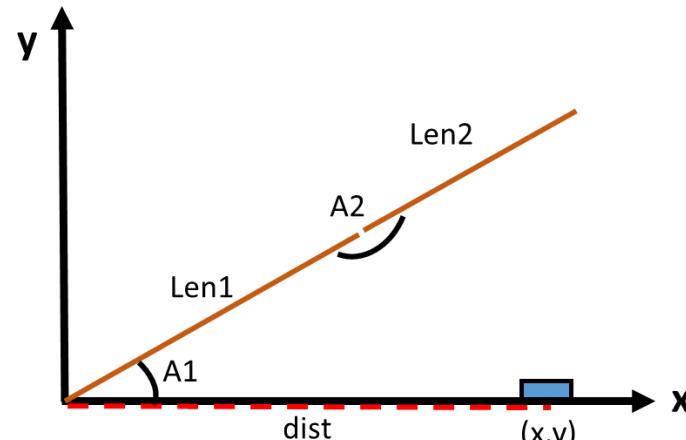
$$C^2 = A^2 + B^2 - 2AB(\cos c)$$

Basic micro-management of the robotic arm

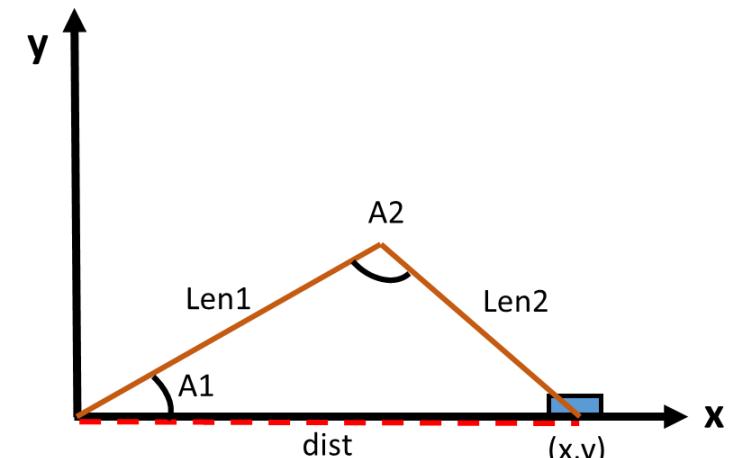
2. Plan the various stages & determine motor angles at each stage



$$\begin{aligned} M1 &= A1 = 90^\circ \\ M2 &= 90^\circ \end{aligned}$$



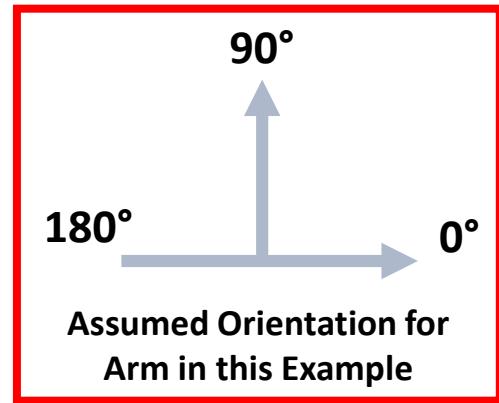
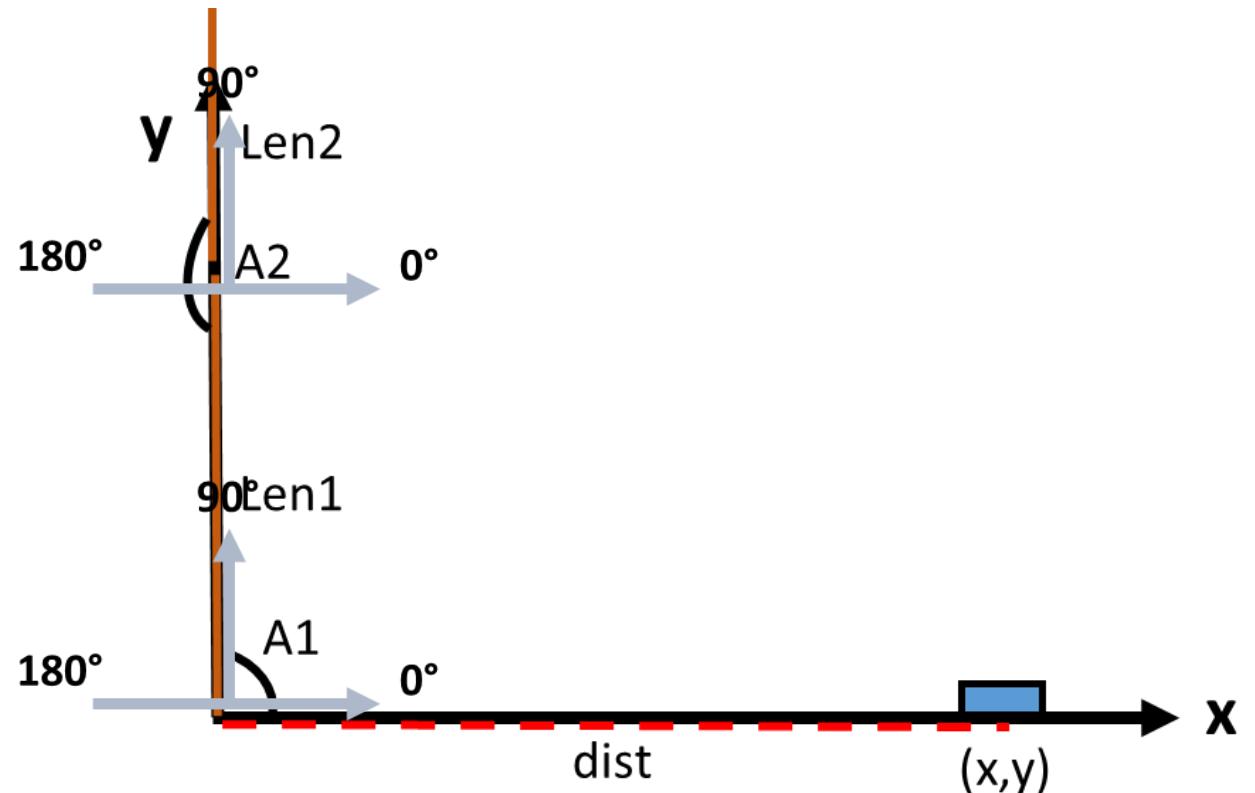
$$\begin{aligned} M1 &= A1 \\ M2 &= 90^\circ \end{aligned}$$



$$\begin{aligned} M1 &= A1 \\ M2 &= 90 - (180 - A2) \end{aligned}$$

Basic micro-management of the robotic arm

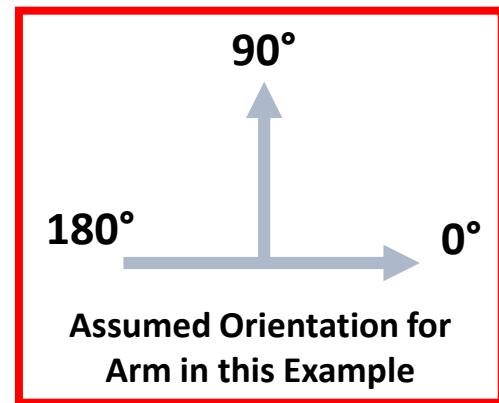
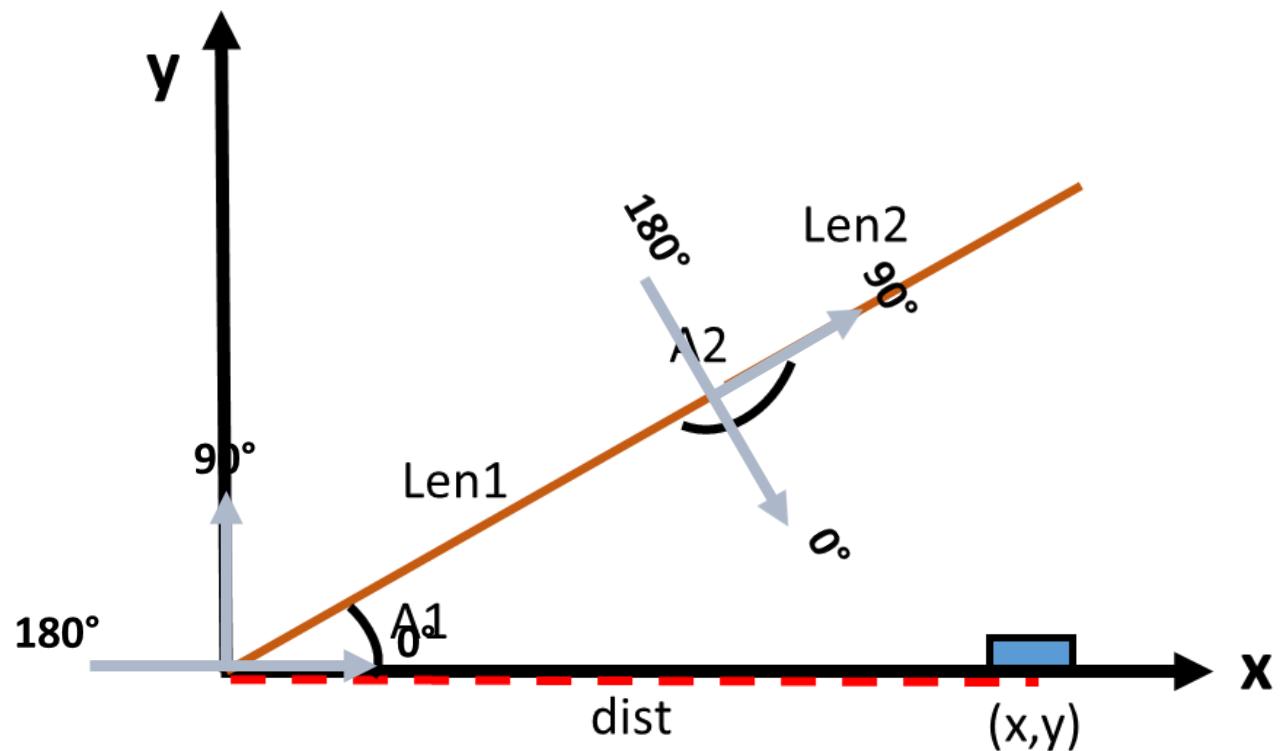
2. Plan the various stages & determine motor angles at each stage



$$\begin{aligned} M_1 &= A_1 = 90^\circ \\ M_2 &= 90^\circ \end{aligned}$$

Basic micro-management of the robotic arm

2. Plan the various stages & determine motor angles at each stage

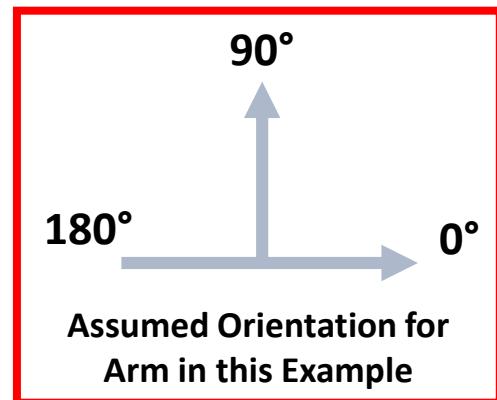
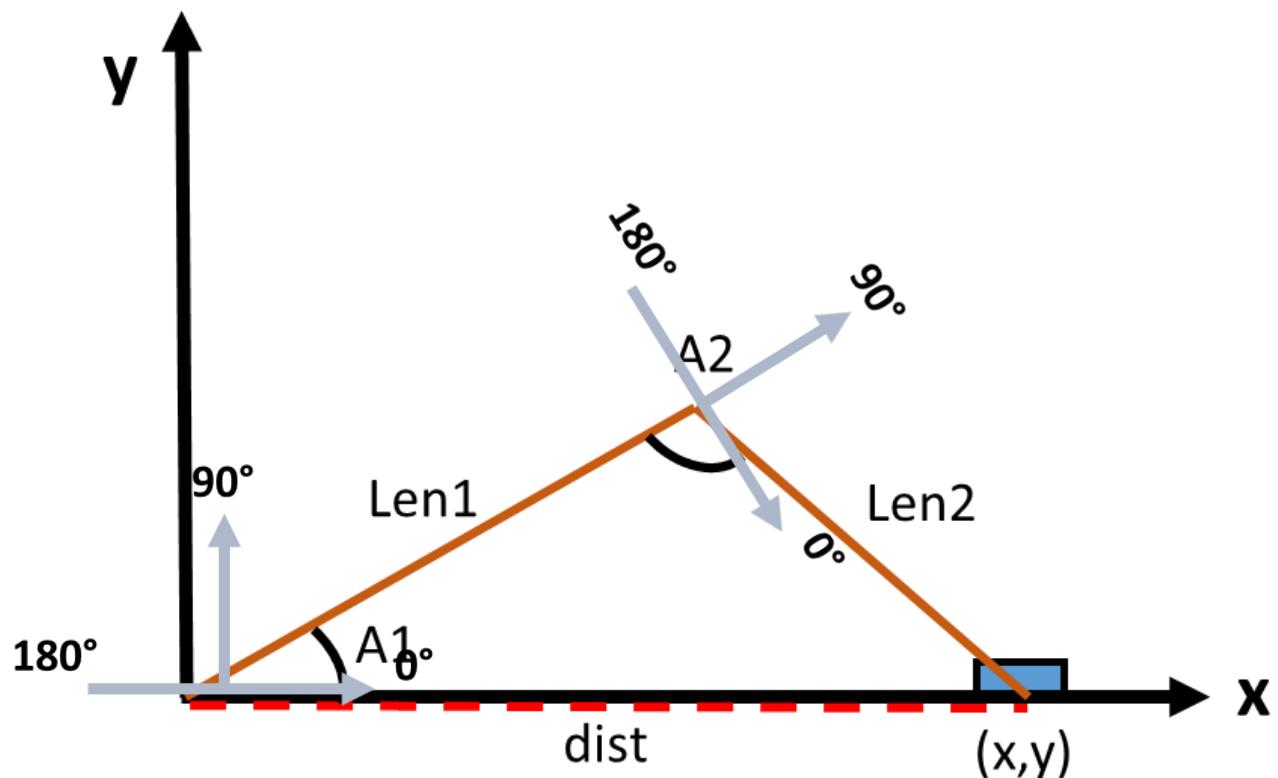


$$M1 = \alpha_1$$

$$M2 = 90^\circ$$

Basic micro-management of the robotic arm

2. Plan the various stages & determine motor angles at each stage

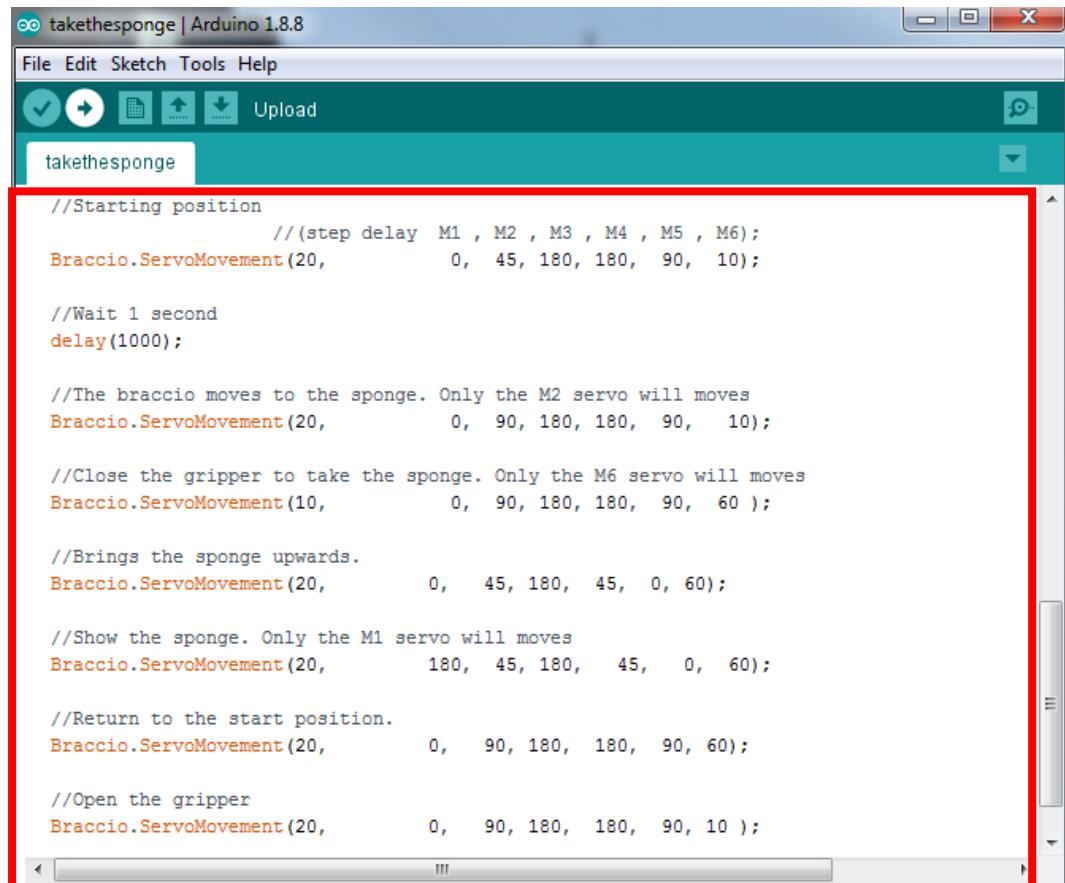


$$M_1 = A_1$$

$$M_2 = A_2 - 90$$

Basic micro-management of the robotic arm

3. Configure and execute codes in control software



```

#!/usr/bin/env python
# works for actual OM ONLY!
# does not work for actual OM_with_TB3

import rospy                                     #import the python library for ROS
from open_manipulator_msgs.msg import JointPosition   #import JointPosition message
from open_manipulator_msgs.srv import SetJointPosition
import math

def talker():
    rospy.init_node('OM_publisher') #Initiate a Node called 'OM_publisher'
    set_joint_position = rospy.ServiceProxy('/open_manipulator/goal_joint_space_controller', SetJointPosition)
    set_gripper_position = rospy.ServiceProxy('/open_manipulator/goal_tool_controller', SetGripperPosition)

    while not rospy.is_shutdown():
        joint_position = JointPosition()
        joint_position.joint_name = ['joint1', 'joint2', 'joint3', 'joint4']
        joint_position.position = [-0.5, 0, 0.5, -0.5]           # in radians
        resp1 = set_joint_position('planning_group', joint_position, 3)
        gripper_position = JointPosition()
        gripper_position.joint_name = ['gripper']
        gripper_position.position = [0.01]      # 0.01 for fully close and open
        resp2 = set_gripper_position('planning_group', gripper_position, 3)

if __name__ == '__main__':
    try:
        talker()
    except rospy.ROSInterruptException:
        pass

```

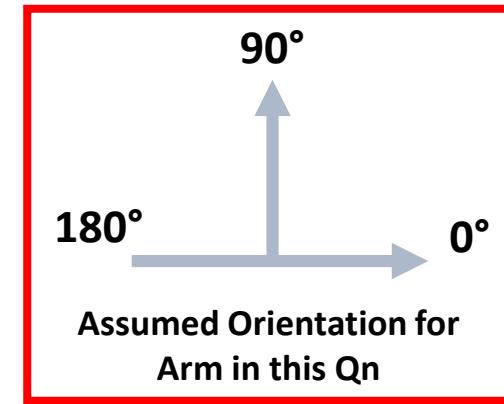
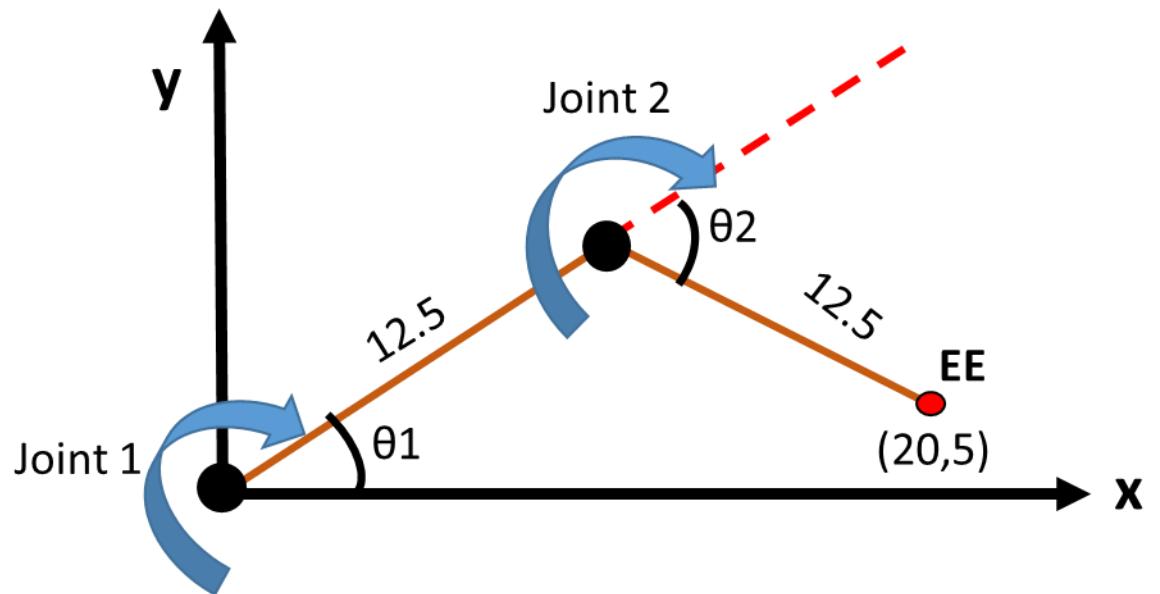
Chapter 6: Group Discussion – Inverse Kinematics Practices

Inverse Kinematics Practices

1. 3 DOF robotic arm; uses same motors and control software as the Braccio Robotic Arm
2. 6 DOF Tinkerkit Braccio Robotic Arm
3. 3 DOF robotic arm; uses a different set of motors and control software

Let's do this together: Practice 1:

Based on the following 3 DOF robotic arm, **calculate the reference angles (i.e. θ_1 and θ_2) and motor angles (i.e. M_1 and M_2)**; its motor orientation is same as the Braccio Robotic Arm (illustrated below). Assume that the motors used at each joint for this robotic arm are the same and that the motor at the end effector (EE), M_3 , is not in use. The aim is to get the EE of the arm to reach at x-y position (20, 5). Refer to diagram below for better illustration; all lengths are in cm.



Let's do this together: Practice 2:

Based on the 6 DOF Braccio Robotic Arm, **calculate the unknown reference angles and motor angles**; its motor orientation is illustrated below. Assume that the motors used at each joint for this robotic arm are the same, and that M1 and M6 are known. The aim is to get the end effector (EE) of the arm to reach at x-y position (25, 0). Refer to diagram below for better illustration; the physical specifications of the robotic arm is stated in the table below. State any assumptions made if necessary.

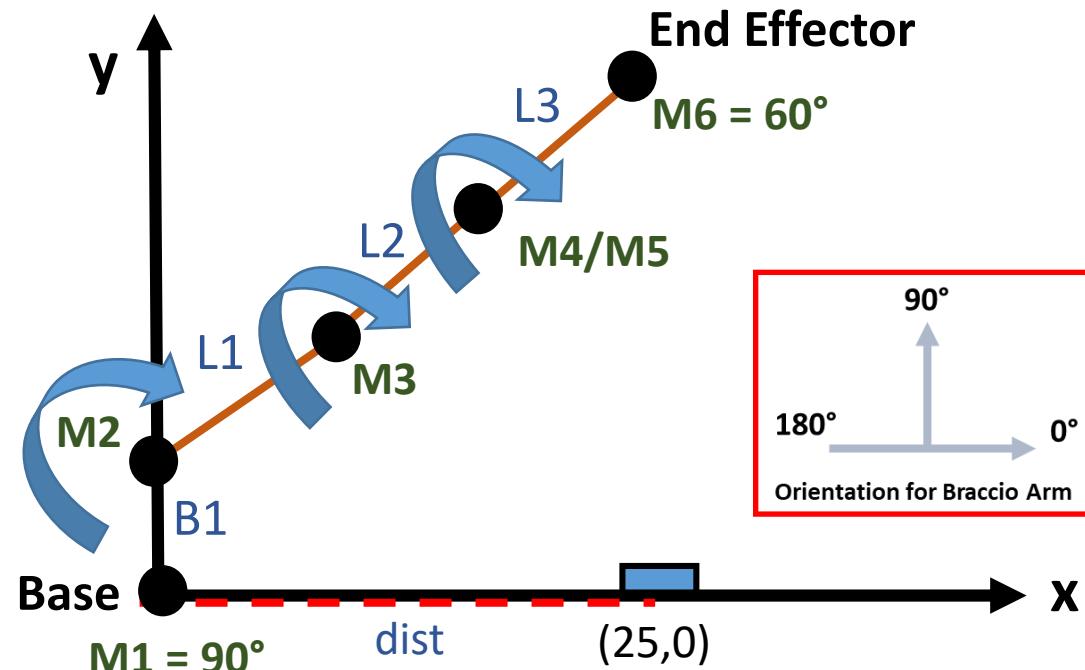
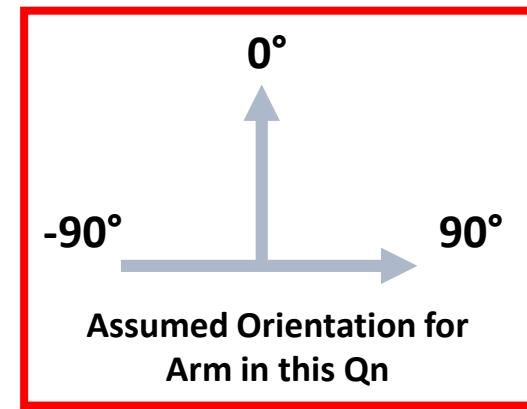
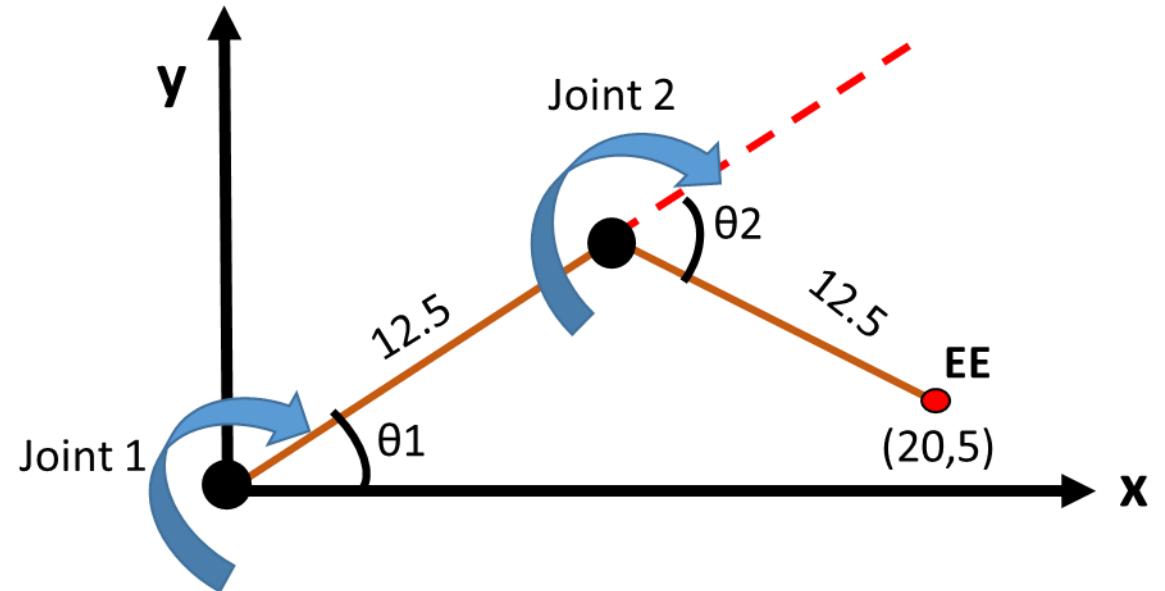


Table 1: Physical Specifications of robotic arm and other details

L1	12.5 cm
L2	12.5 cm
L3	19.4 cm
B1	7.5 cm
dist	25 cm
Position of box	(25, 0)

Let's do this together: Practice 3:

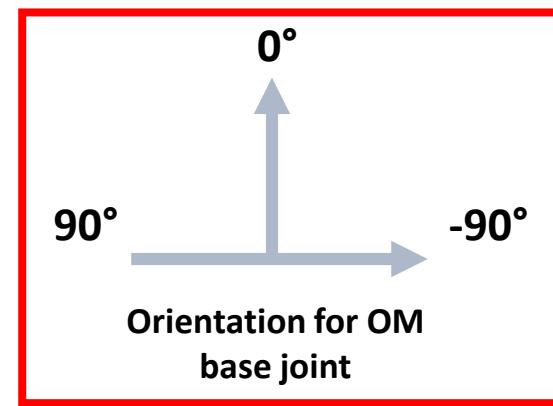
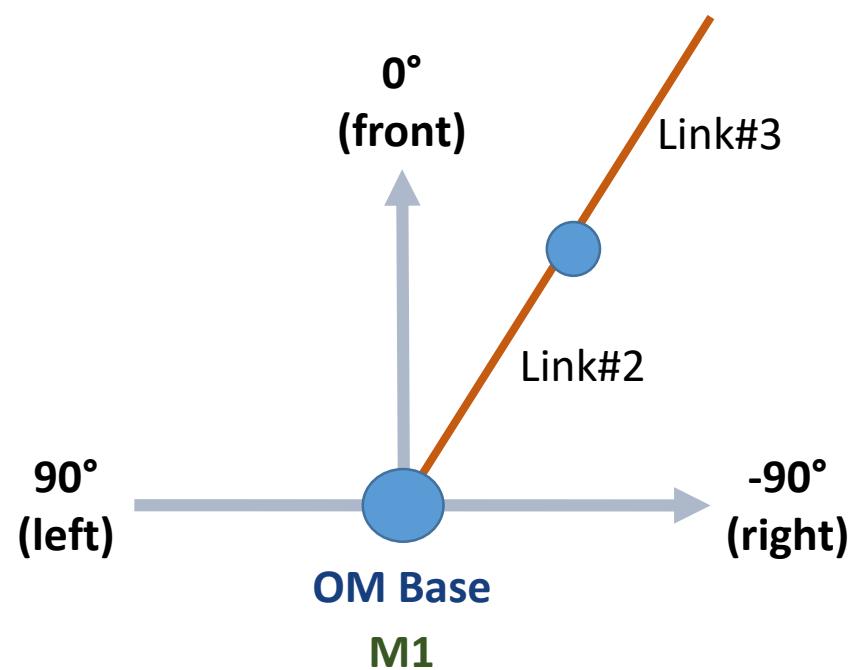
Based on the following 3 DOF robotic arm, **calculate the reference angles (i.e. θ_1 and θ_2) and motor angles (i.e. M_1 and M_2)**; its motor orientation is illustrated below. Assume that the motors used at each joint for this robotic arm are the same and that the motor at the end effector (EE), M_3 , is not in use. The aim is to get the EE of the arm to reach at x-y position (20, 5). Refer to diagram below for better illustration; all lengths are in cm.



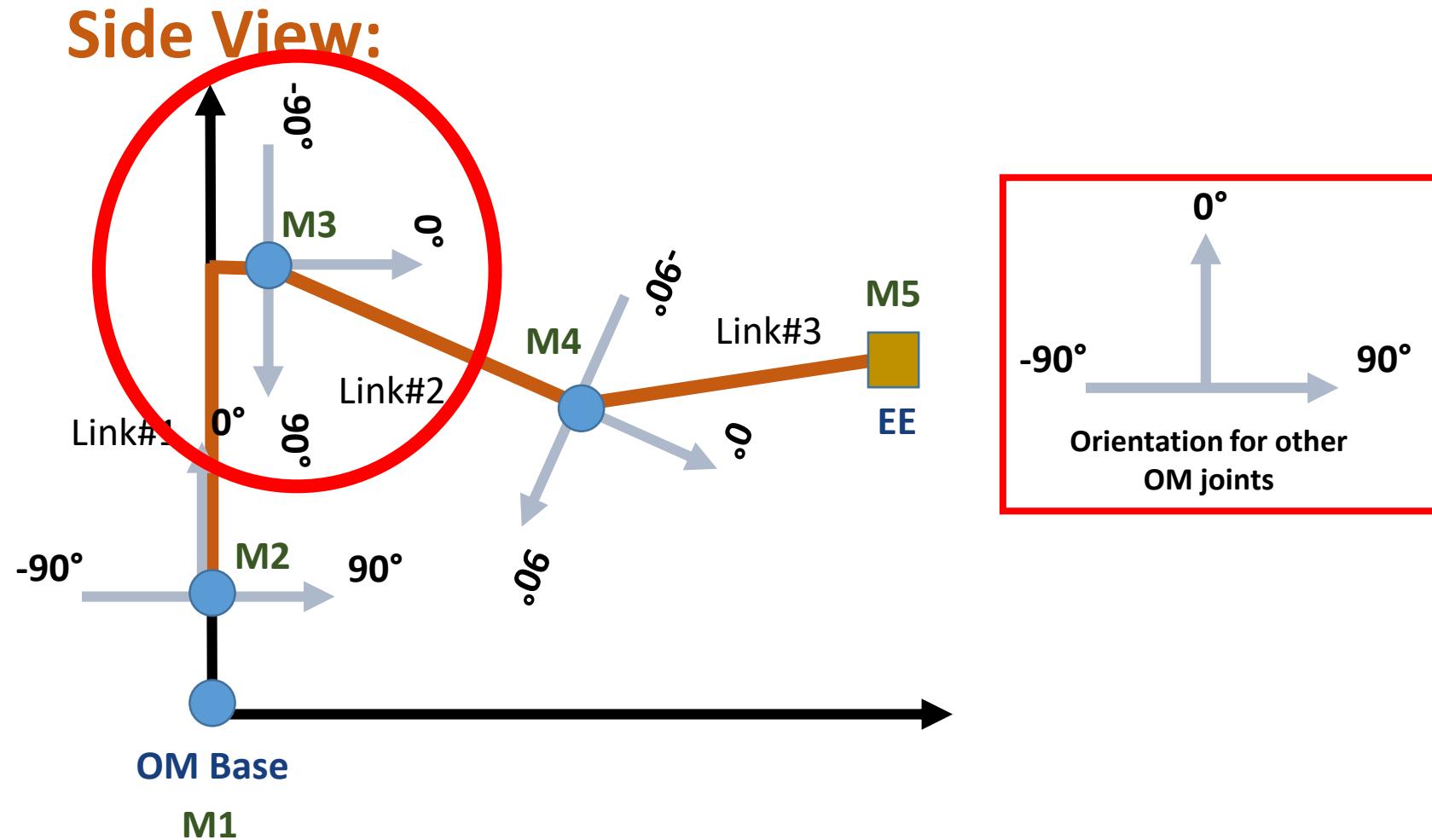
Chapter 7: Group Project – Controlling and configuring the OM to execute tasks

Motor Orientation for OM (Base Joint)

Top View:



Motor Orientation for OM (Other Joints)



Group Project 1: Pick up and Place the item

Robotic arms are currently and widely utilized by automotive factories to aid in manufacturing processes. As mentioned earlier, the main challenge that engineers face when building robotic systems is to develop program(s) to obtain coordinated movements within all the joints in order to achieve precise and safe control.

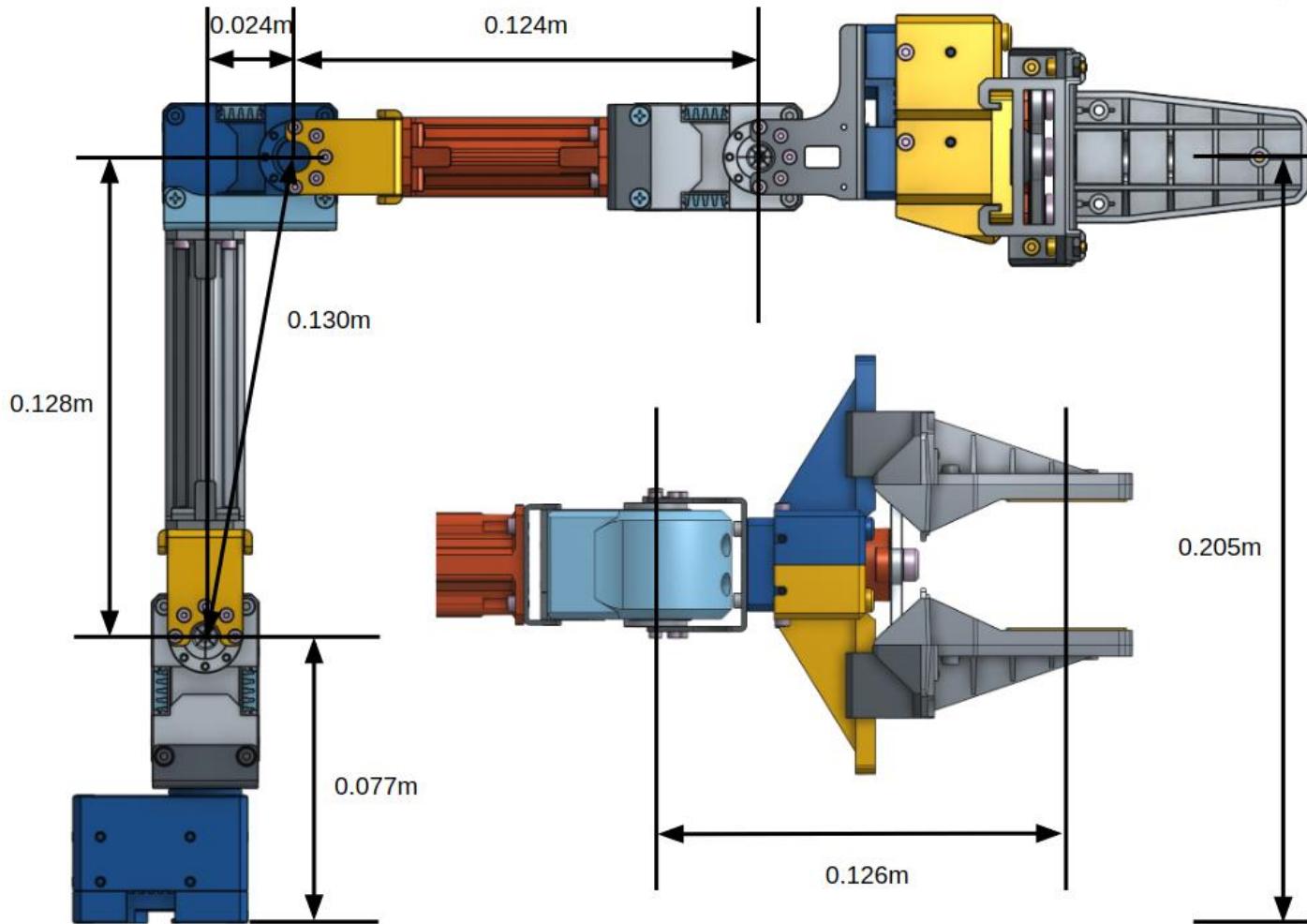
In your respective groups, **develop a ROS node that can control the OM Robotic Arm (that is placed on the Turtlebot3 base) to successfully pick up a given item from a fixed ground location and place it on another ground location, without colliding with any other objects. You are to submit your working calculations and python codes at the end of this project.**

Before executing the ROS node to try out, please call out to me to assess your attempt. If your attempt fail, you are to revise your calculations/codes and try again.
Hints: Use `control.om.py` as a template to build your codes; you will also need to use `rospy.sleep()` codes in between each step.

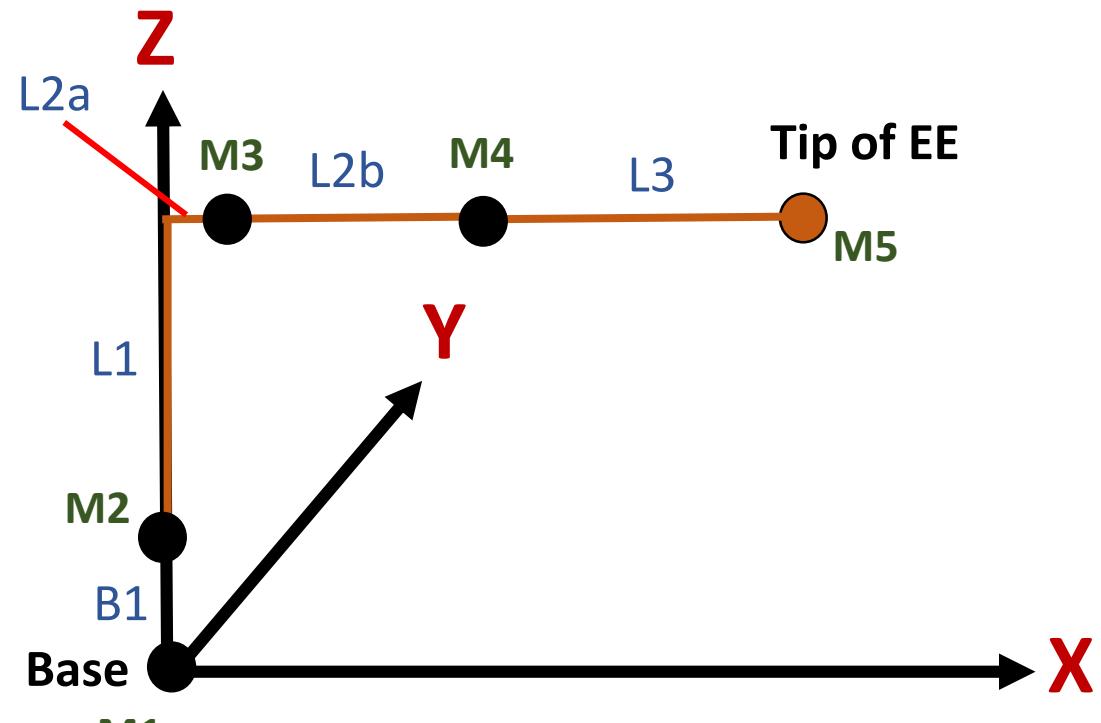
Note: You can refer to the next few slides for the specifications of the robotic arm and other required details that you need to know (i.e. positions of the item).

Group Project 1: Pick up and Place the box

Specifications of the robotic arm:



Group Project 1: Pick up and Place the box



*Figure is not drawn to scale

Physical Specifications of robotic arm and other details

L1	12.8 cm
L2a	2.4 cm
L2b	12.4 cm
L3	12.6 cm
B1	7.7 cm
dist	30.12 cm
Initial Position (IP) of item (x-y-z)	[0, 30.12, 5]
Final Position (FP) of item (x-y-z)	[0, -30.12, 5]

Group Project 1: RECAP

To control the OM,

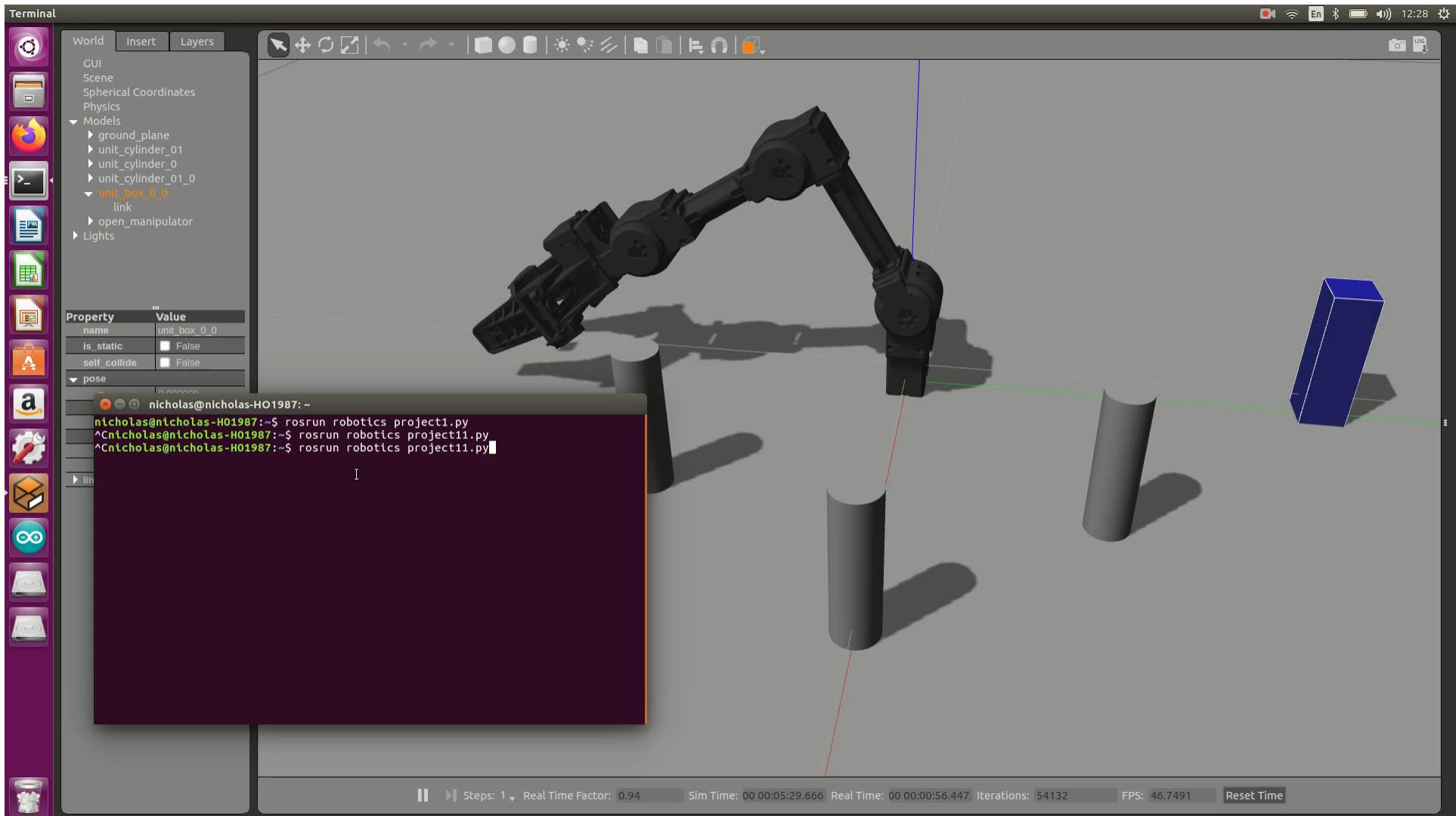
1. Run \$ roscore on one terminal
2. Prepare the setup for the OM: Connect the wires, switch on the power, and manually bring up the OM
3. On another terminal, activate the controller; this will lock the motors

```
$ roslaunch open_manipulator_controller  
open_manipulator_controller.launch
```

4. ROSRUN your codes

```
$ rosrun robotics Project1.py
```

Group Project 1: Ideal Output



Chapter 7: Summary & Conclusion

Summary & Conclusion

- To build a robotic arm system, you will need at least **a robotic arm, a control software, a control board** (i.e. microcontroller), and **a computer (e.g. PC, SBC)**; an extension to the control board may be required to better control the robotic arm (e.g. Tinker Sensor Shield for Braccio Robotic Arm)
- The **main challenge in developing reliable robotic systems is the code development process**, which affects the level of precise and coordinated control
- To micro-manage the robotic arm, you will need to (a) **Determine the reference angles required**, (b) **Plan the various stages & determine motor angles at each stage**, (c) **Configure and execute codes in the control software**

Thank you!
Questions?