UNIVERSITÄT SIEGEN
University of Siegen
Faculty of Natural Sciences and Engineering

Introduction to The Robot Operating System (ROS)

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Lehrstuhl für Regelungs- und Steuerungstechnik

ROS

Agenda

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- **ROS Concepts**
- **Organizing and Building ROS Code**
- **ROS Across Multiple Machines**
- **Lab Assignment**
- **Installing and Configuring ROS Indigo Environment in VirtualBox**
- **Create ROS Catkin Workspace and Package**
- **Configuring EV3 Control Packages in ROS**
- **ROS ⇔ EV3 Communication Setup**
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- **Lego Mindstorms Ev3 Sensors**
- **References**
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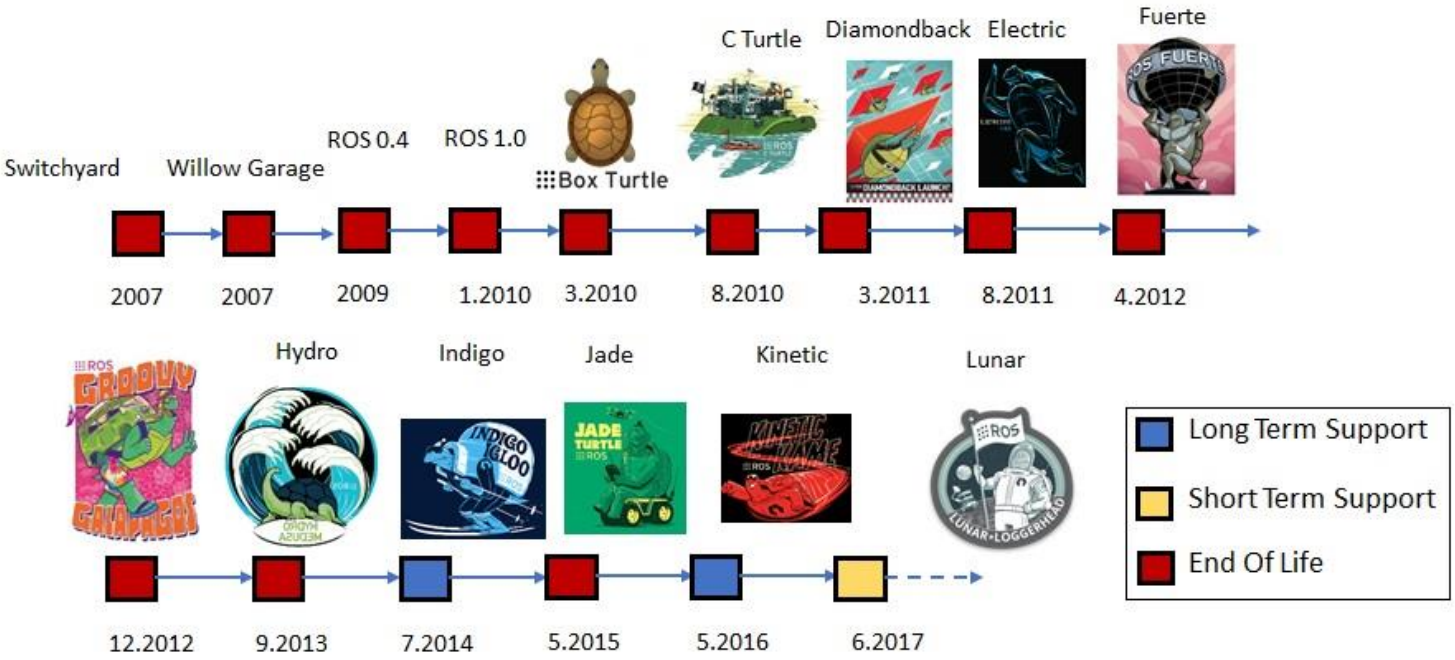
Introduction

The Robot Operating System (ROS)

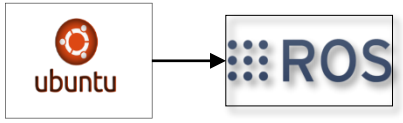
ROS is a flexible framework for writing robot software. It is a collection of tools, libraries, and conventions that aim to simplify the task of creating complex and robust robot behaviour across a wide variety of robotic platforms.



ROS Environment Installation

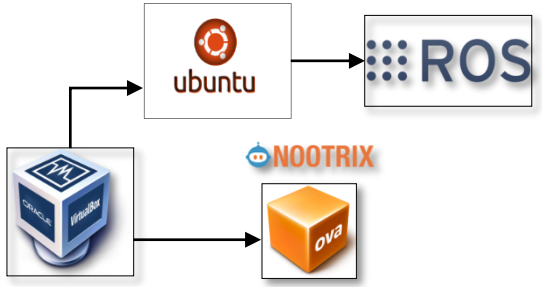
Operating System:

1. Installing ROS desktop-full configuration



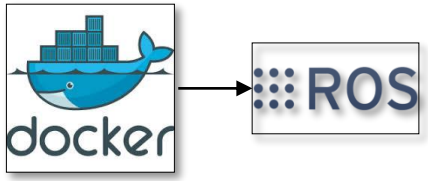
Virtual box:

1. Ubuntu desktop installation + Installing ROS desktop-full configuration.
2. NOOTRIX ’’.ova’’ archive with a preinstalled ROS desktop-full configuration.



Container:

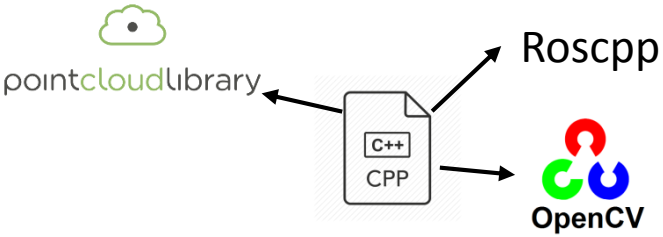
1. Installing ROS container image on Docker.



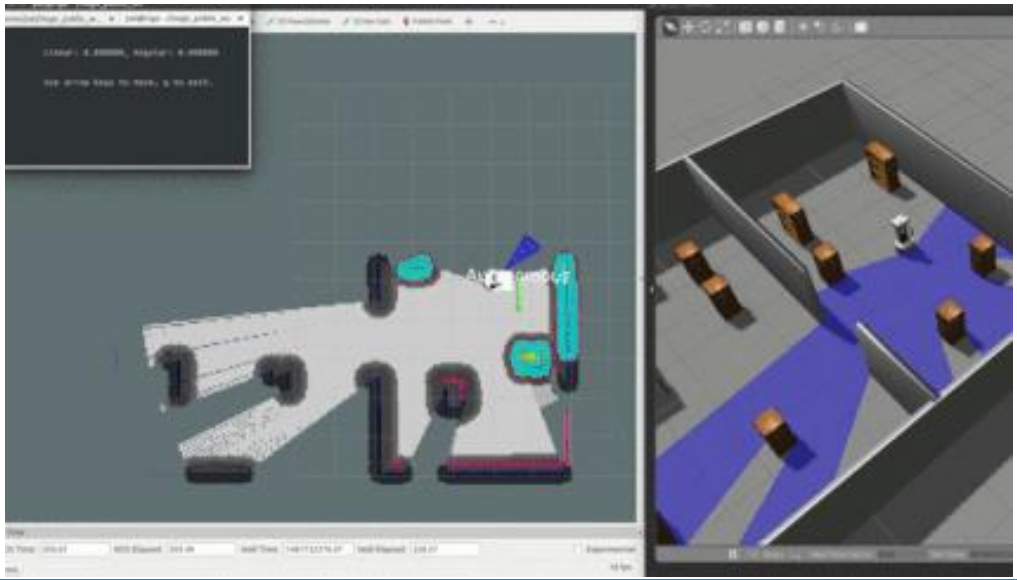
ROS Concepts

ROS Node

A Node is an executable that uses ROS to communicate with other nodes.

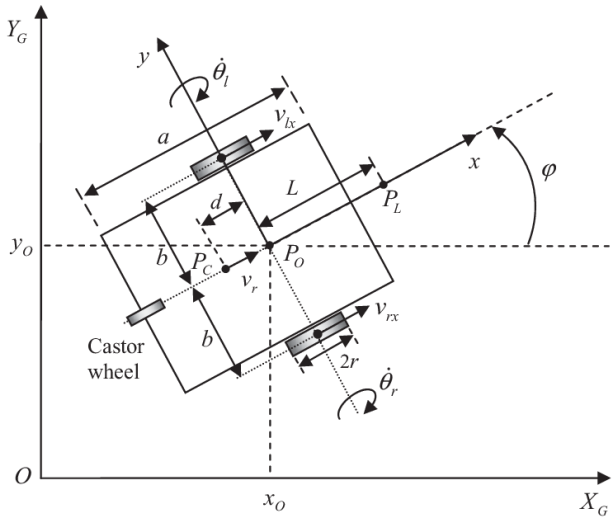


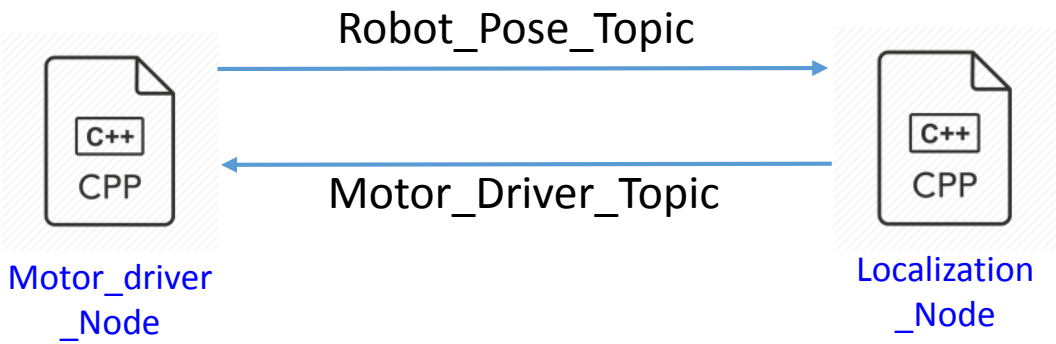

```
#include "....."

int main(int argc, char **argv)
{
    ros::init(argc, argv, "Mapping_Node");

    /* ..... Image Processing Code .....*/

 }
```



Topics

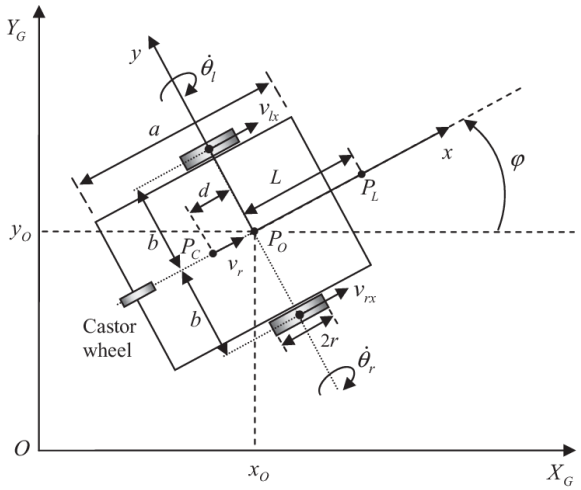
Topics are named buses over which nodes exchange messages. ROS currently supports TCP/IP-based and UDP-based message transport.

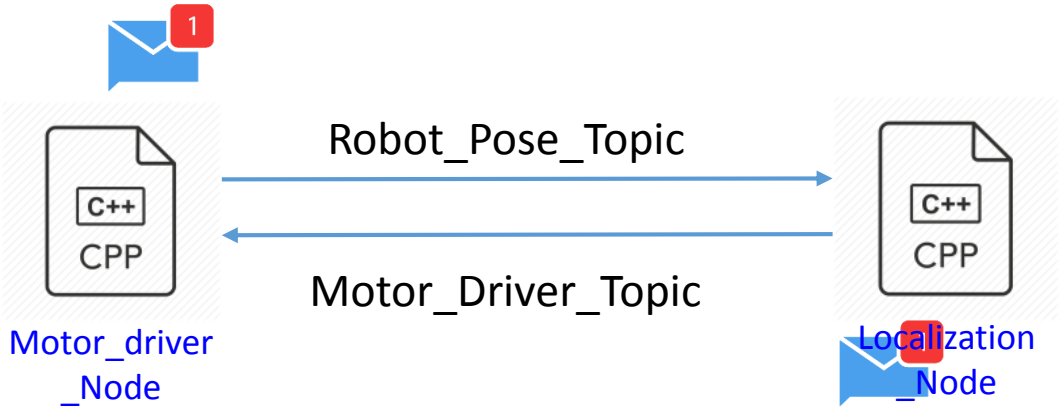




ROS Message

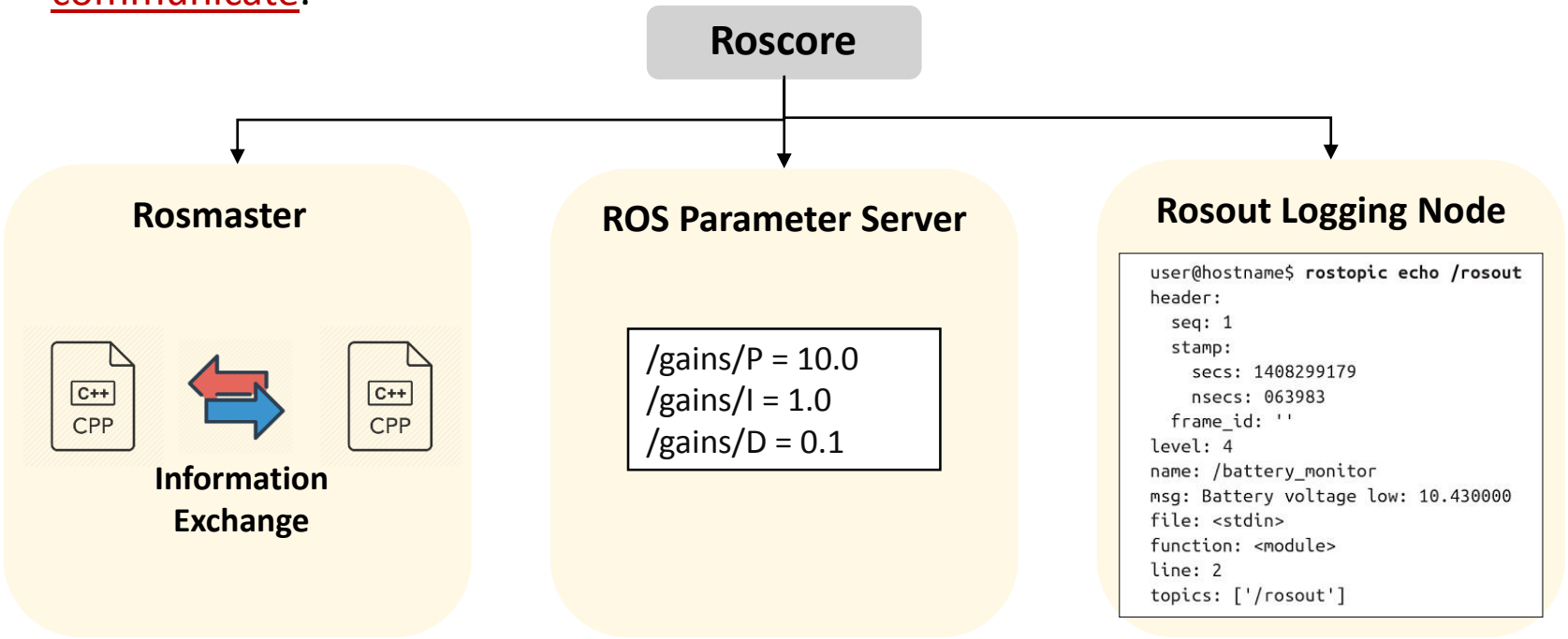
A message is a simple data structure, comprising typed fields. ROS provides a set of standard message formats that cover most of the common use cases in robotics such as Geometric concepts, Sensors, Navigation data, and Diagnostic.



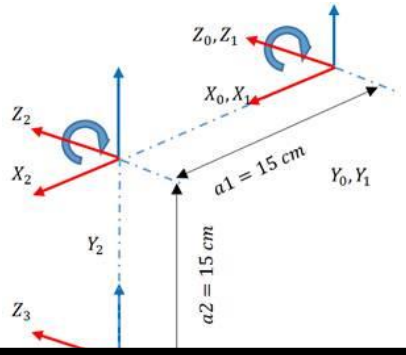


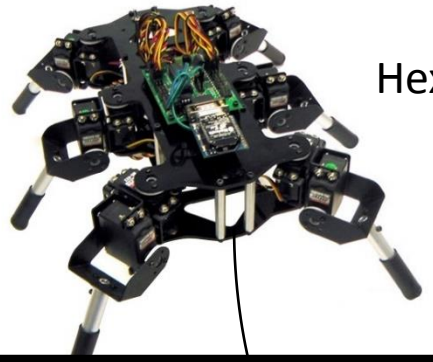
ROS Core

Roscore: is a collection of nodes and programs that are pre-requisites of a ROS-based system. You must have a roscore running in order for ROS nodes to communicate.



Example: Publisher & Subscriber





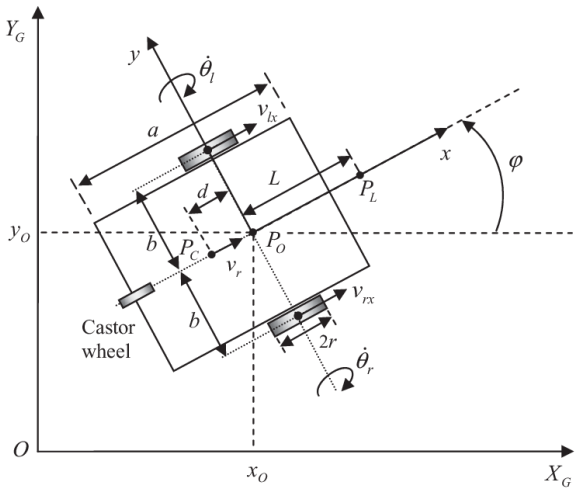
HexaPod

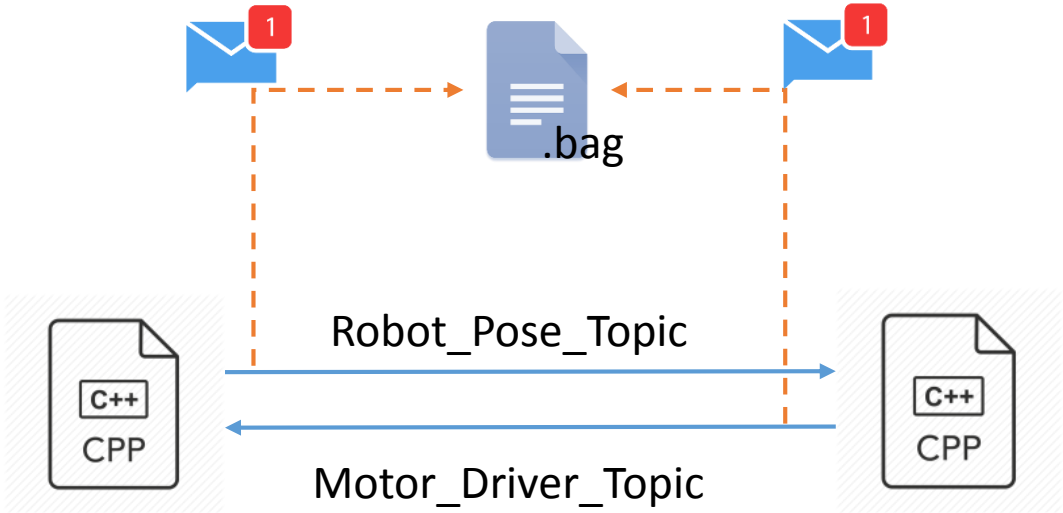
- Nodes
- Message
- Topics
- Master

```
#include “……..."
#include “……..“

void subscriberCallback(const geometry_msgs::PoseStamped::ConstPtr& msg)
{

ROS_INFO("\n \n Tool_pose: (%.2f, %.2f. %.2f) \n orientation:(%.2f, %.2f. %.2f . %.2f) \n", msg ->pose.position.x, msg ->pose.position.y, msg ->pose.position.z, msg ->pose.orientation.x, msg ->pose.orientation.y, msg ->pose.orientation.z, msg ->pose.orientation.w);

}

int main(int argc, char **argv)
{
   ros::init(argc, argv, "subscriber_node");
   ros::Subscriber sub = n.subscribe(“sensor_data", 1000, subscriberCallback);
   ros::spin();

  return 0;
}
```

ROS Bag

A bag is a file format in ROS for storing ROS message data. Bags are typically created by a tool like rosbag, which subscribe to one or more ROS topics, and store the serialized message data in a file as it is received. These bag files can also be played back in ROS to the same topics they were recorded from, or even remapped to new topics.

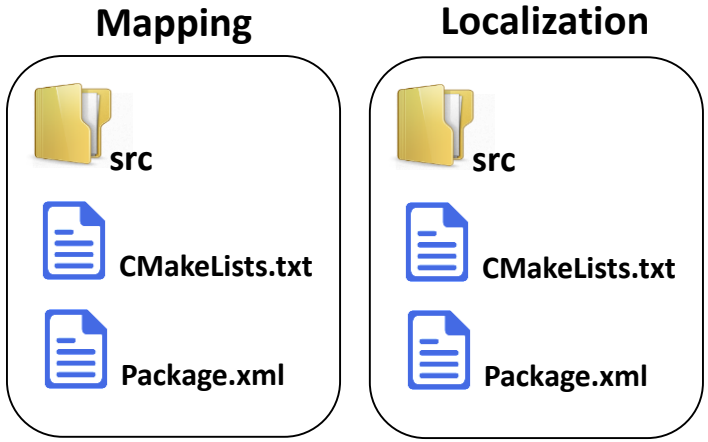


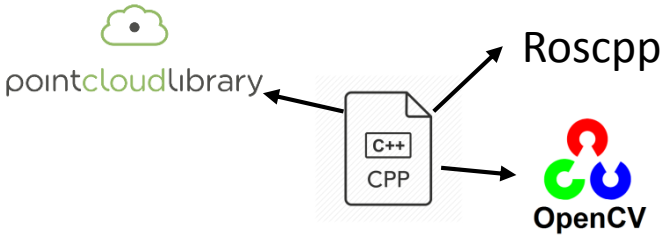


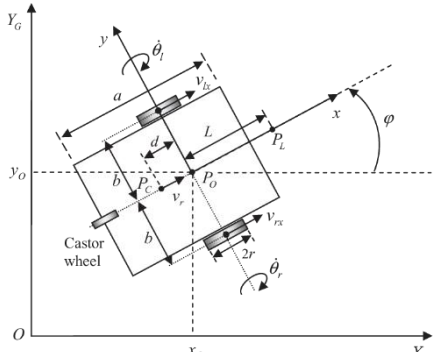
Organizing and Building ROS Code

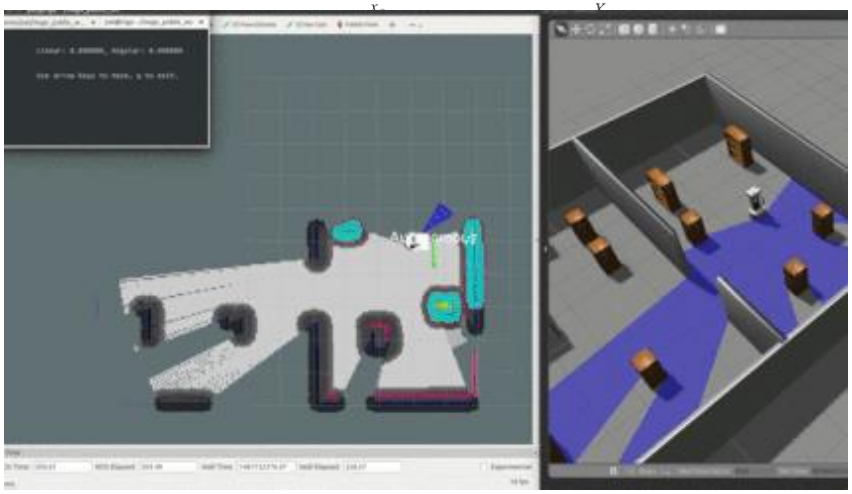
ROS Package

Packages: are the main unit for organizing software in ROS.



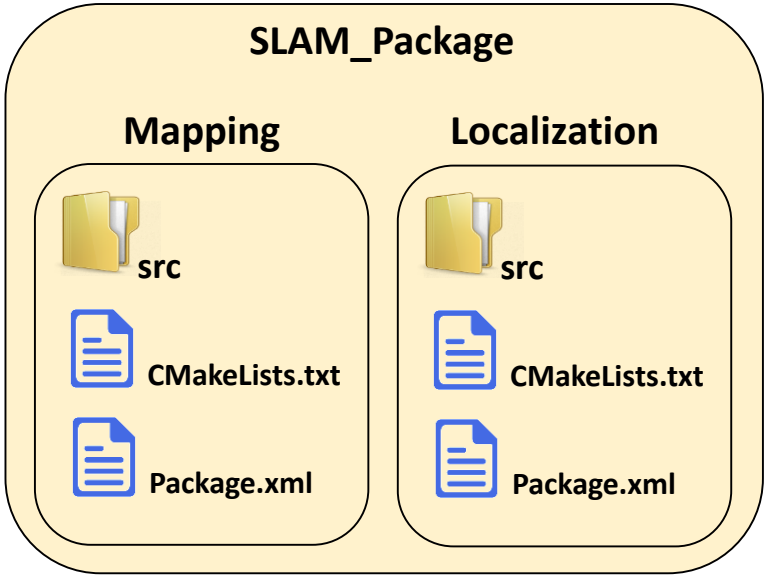


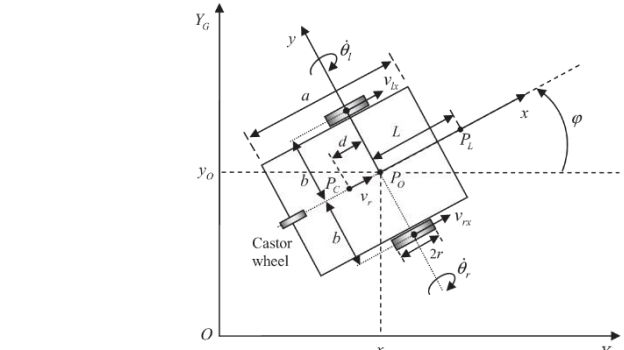


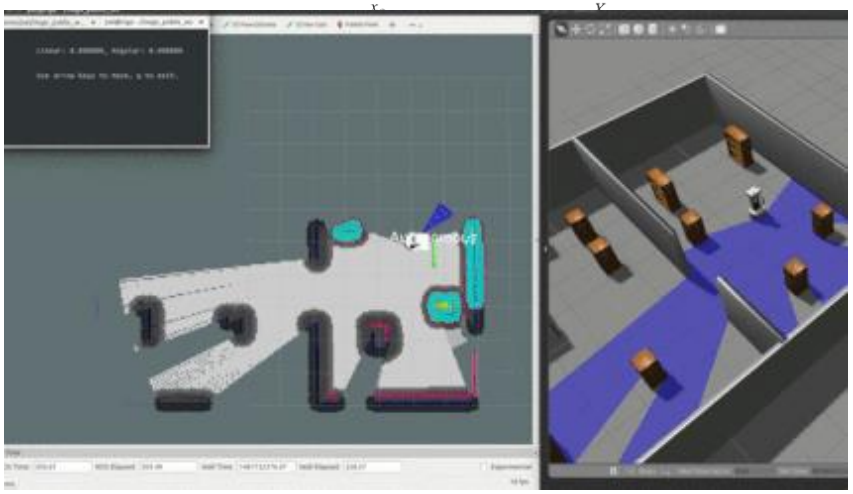


ROS Metapackages

Metapackages: are specialized Packages which only serve to represent a group of related other packages.

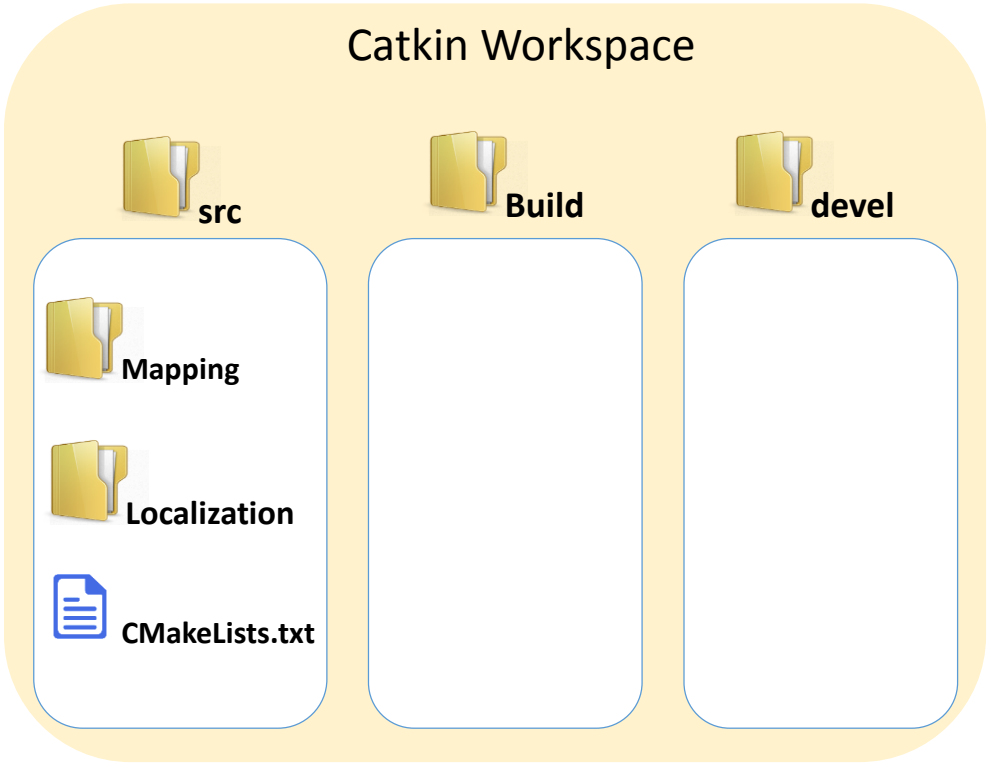


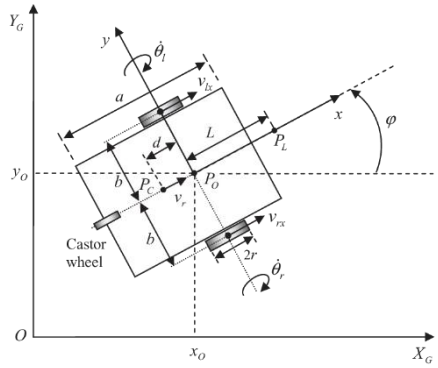




Catkin Workspace

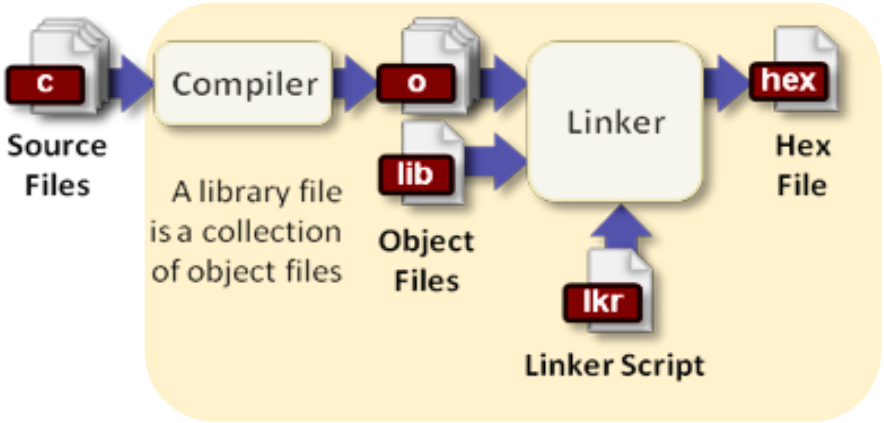
A catkin workspace is a folder where you modify, build, and install catkin packages.





What is a Build System?

A **build system** is responsible for generating 'targets' from raw source code that can be used by an end user.



Build System

CMake

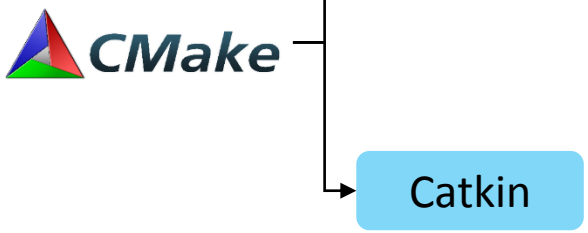
Microsoft® Visual Studio®

eclipse

GNU

ROS Custom Build System

"ROS utilizes a custom build system, that extends CMake to manage dependencies between packages."

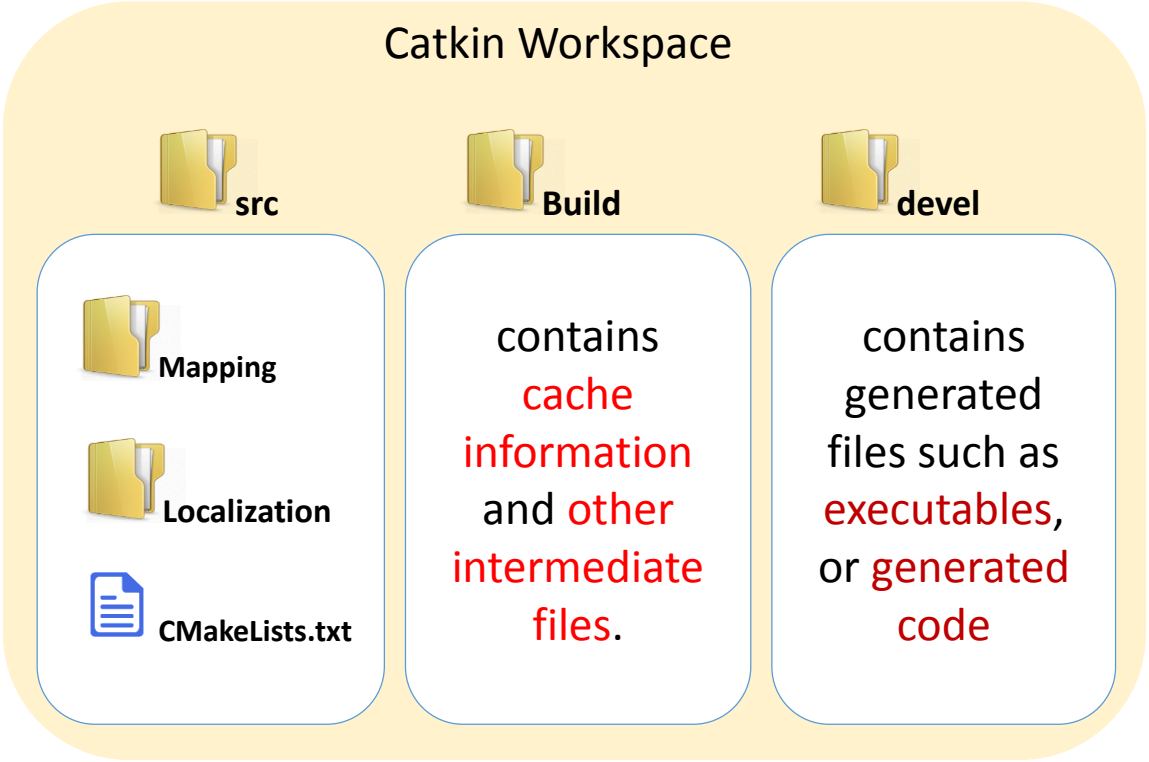


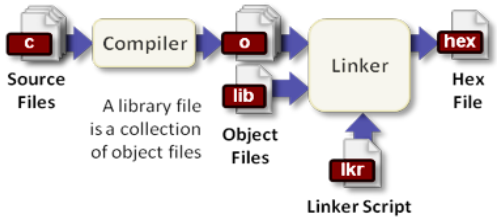
Drawbacks

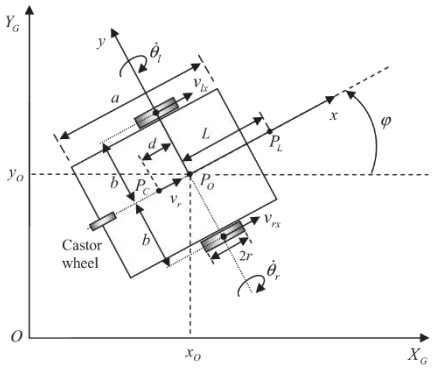
- Rapid growth of the ROS.
- The difficulty of installing ROS on other operating systems.
- Low build speed.

Catkin Workspace

A catkin workspace is a folder where you modify, build, and install catkin packages.



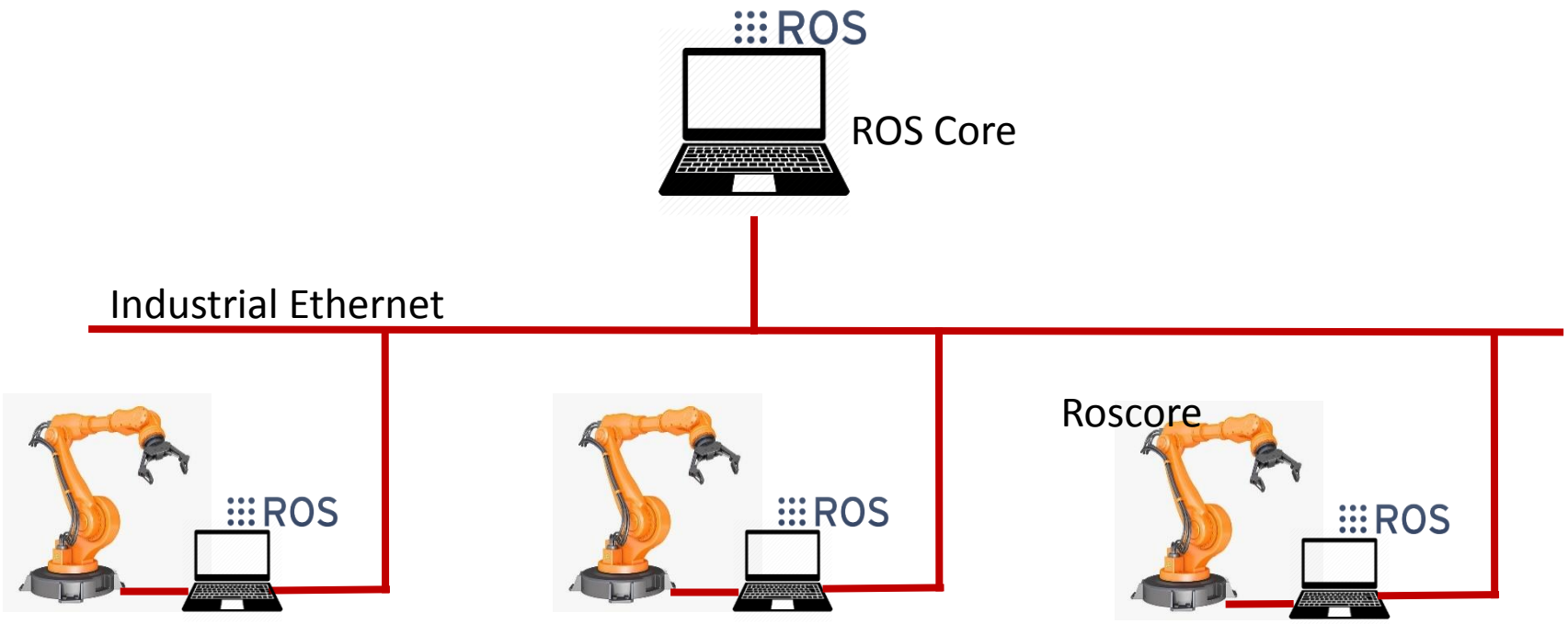




ROS Across Multiple Machines

ROS Network Configuration Requirements

ROS is a distributed computing environment. As a result, ROS has certain requirements of the network configuration:



ROS Network Setup

- **ROS_MASTER_URI:** is a required setting that tells nodes where they can locate the master.
- **ROS_IP** and **ROS_HOSTNAME** are optional environment variable that sets the declared network address of a ROS Node or tool.

ROS_MASTER_URI=http://192.168.0.101:11311
ROS_HOSTNAME=Turtelbot

ROS_MASTER_URI=http://192.168.0.101:11311
ROS_HOSTNAME=PC

Lab Assignment #2: Extending Publisher and Subscribe Node to Send and Receive Sensor Data

Task Pre-requirements

1. Installing and Configuring ROS Indigo Environment in a VirtualBox. ‘‘Tutorial#1’’
2. Create a ROS Catkin Workspace. ‘‘Tutorial#2’’
3. Download course packages in the source space directory. ‘‘Tutorial#2’’

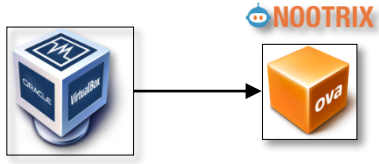
Tutorial #1:
Installing and Configuring ROS Indigo Environment in VirtualBox

Installing ROS Indigo in VirtualBox

1. The first thing you have to do, is to obtain VirtualBox. Visit the VirtualBox website's download page. Install it the same way as any normal Windows program.

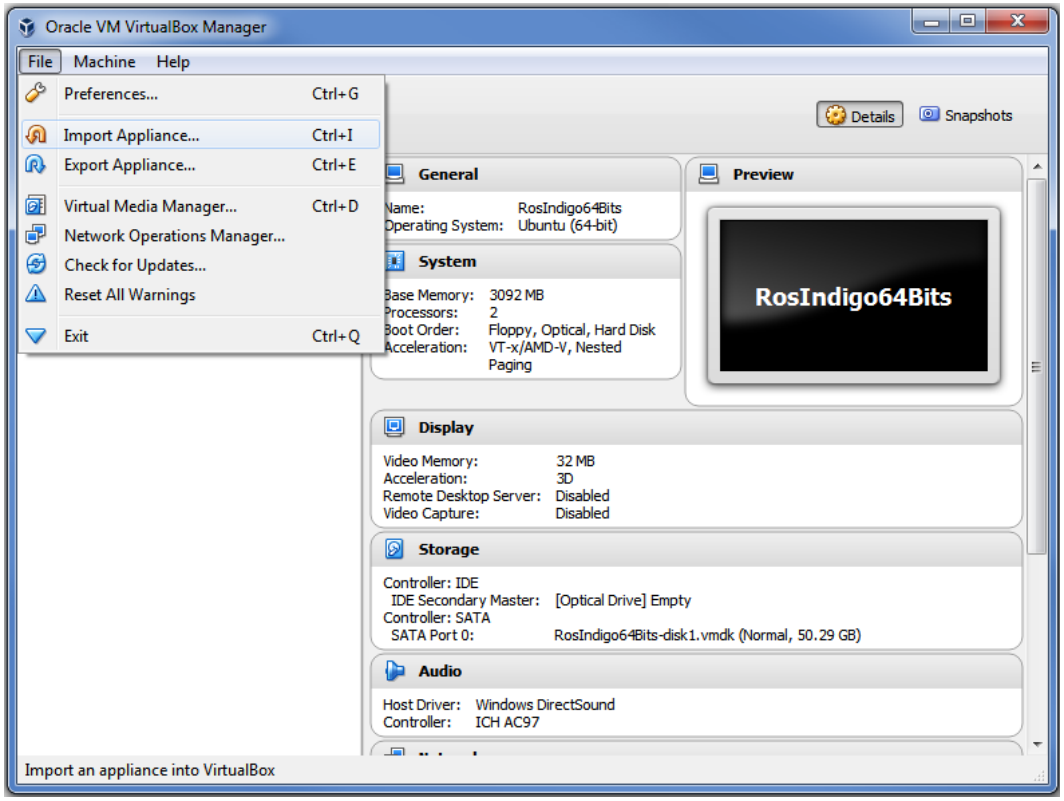
https://www.virtualbox.org/wiki/Downloads

2. Download ROS indigo OVA file archive from >>>>>



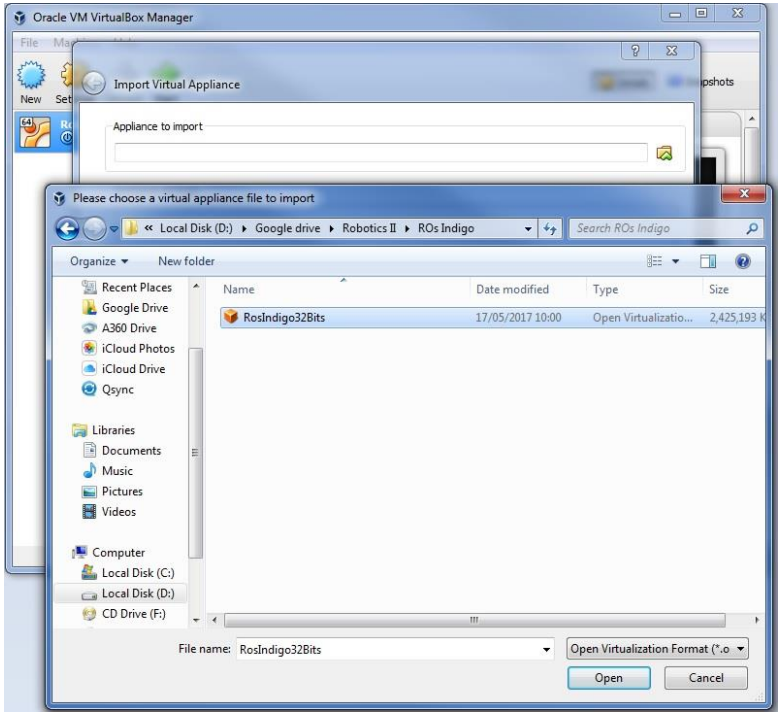
Installing ROS Indigo in VirtualBox

3. After you launch VirtualBox from the Windows Start menu, click on File menu and choose Import Appliance.



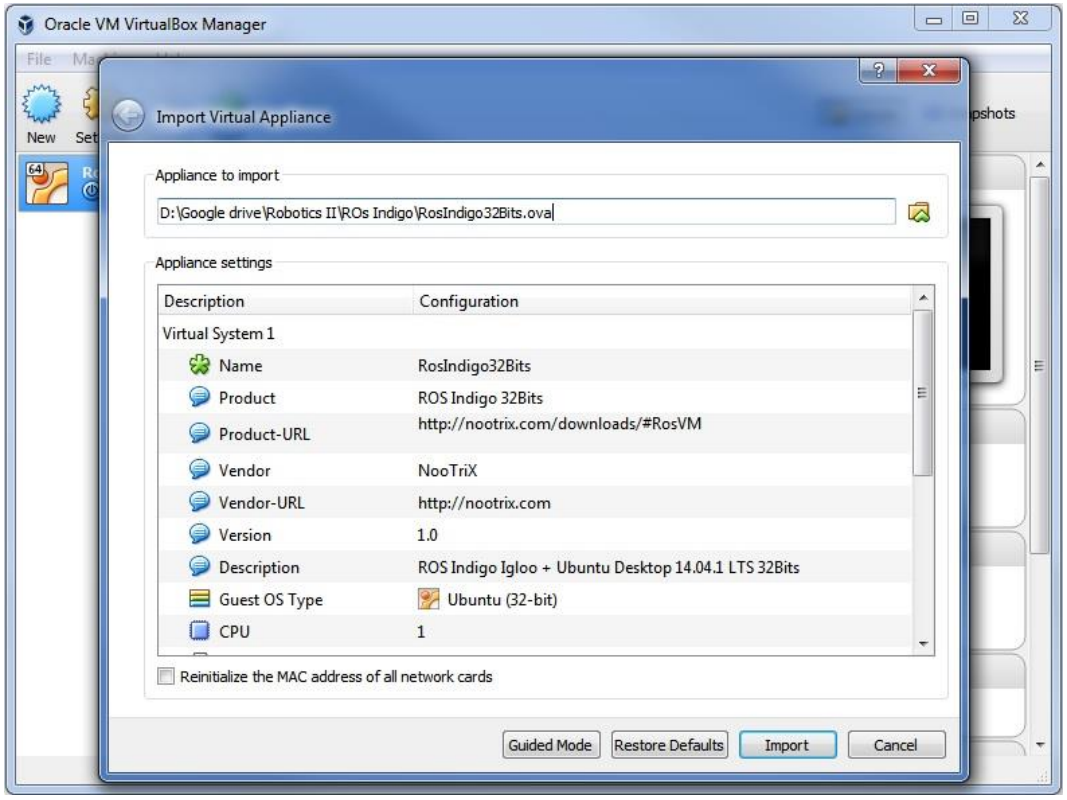
Installing ROS Indigo in VirtualBox

4. In the Appliance Import section, choose the virtual appliance file to import Which in our case the Rosindigo32Bits.ova File. You can choose between 32Bits or 64Bits according to your windows version.



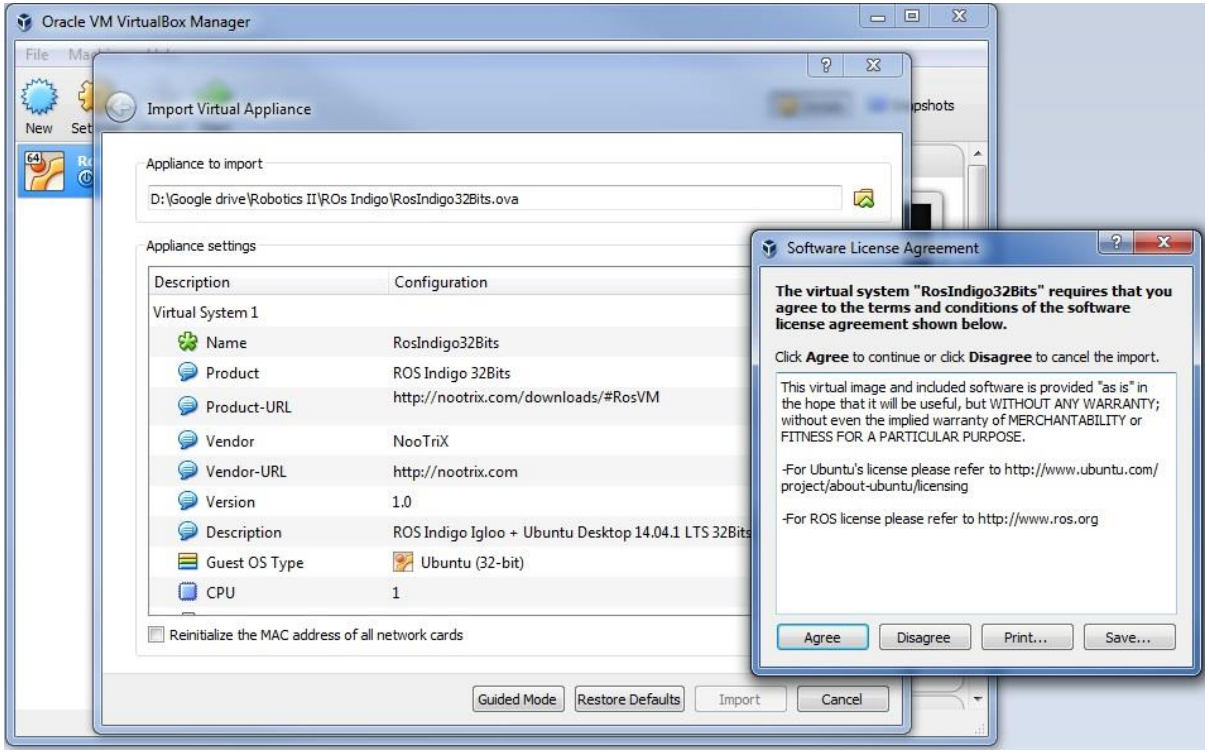
Installing ROS Indigo in VirtualBox

5. Now we are ready to choose Import.



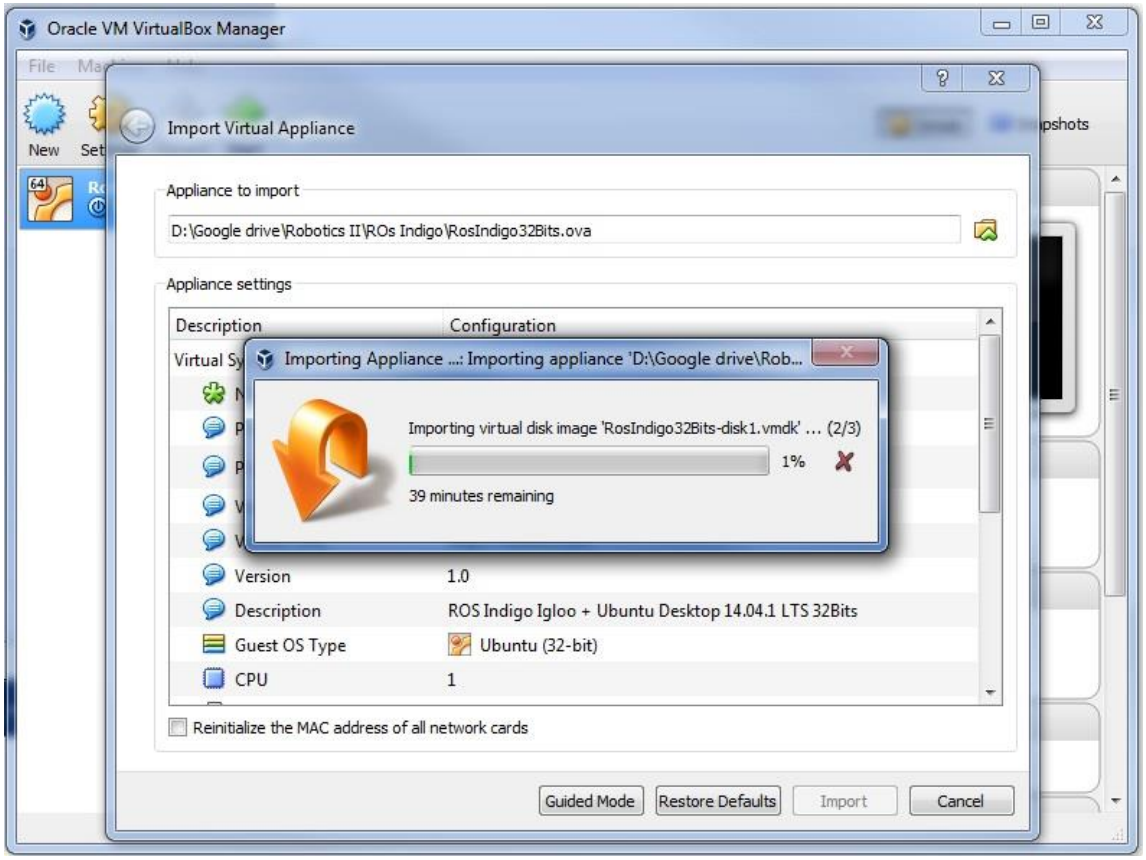
Installing ROS Indigo in VirtualBox

6. A new dialog will appear and asks if we agree to the software terms and conditions, you can press agree to continue.



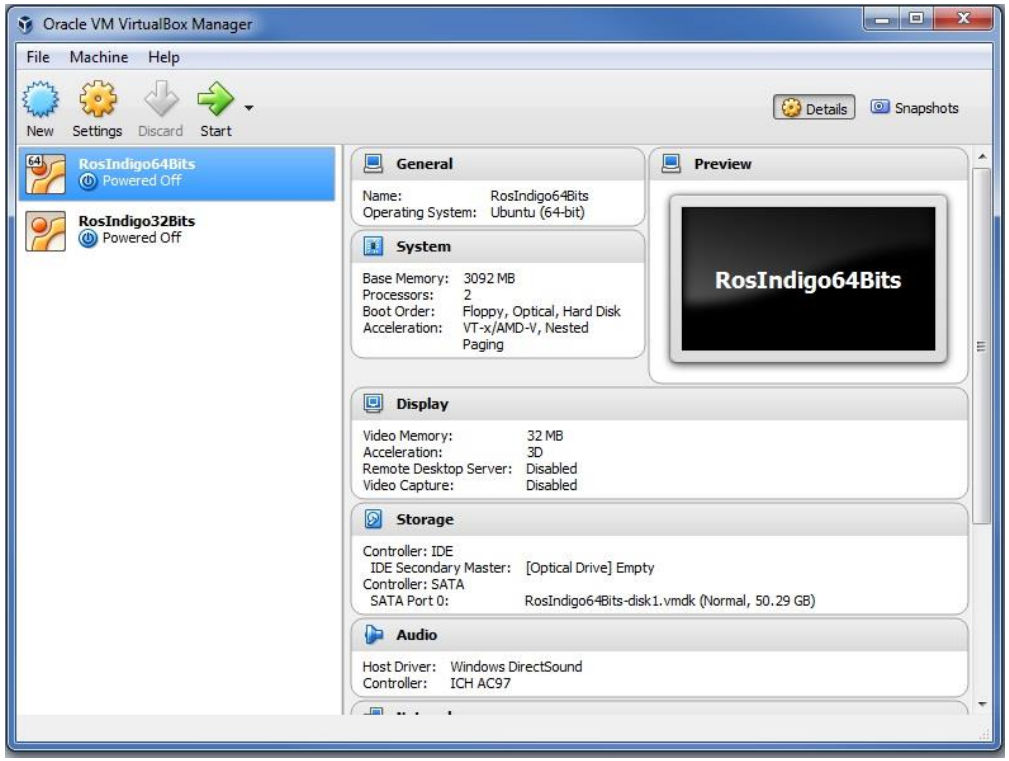
Installing ROS Indigo in VirtualBox

7. Now VirtualBox will start importaing our .ova file.



Installing ROS Indigo in VirtualBox

8. Once it is finished, you will find ROS Indigo in the list of the installed virtual machines. Now you can select it, and press start.



Tutorial #2:
Create a ROS Catkin Workspace and Package

Create and Build a Catkin Workspace

1. Create a catkin_ws directory

```
$ mkdir -p ~/catkin_ws/src
$ cd ~/catkin_ws/
```

2. Using catkin_make command will create a CMakeLists.txt link in the 'src' folder. Additionally, a 'build' and 'devel' folder are created.

```
$ catkin_make
```

3. Source your new setup.*sh file:

```
$ source devel/setup.bash
```

4. Ensure ROS_PACKAGE_PATH environment variable includes the directory we are in. ‘‘/home/youruser/catkin_ws/src:/opt/ros/kinetic/share’’

```
$ echo $ROS_PACKAGE_PATH
```

Course Packages

1. Extract the downloaded course packages in the source directory folder.
2. Now you need to build the downloaded packages in the catkin workspace:

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

“Tutorial#3”
Configuring EV3 Control Packages in ROS

Configuring EV3 Control Packages

1. First change to the catkin workspace

```
$ cd ~/catkin_ws
```

2. Now we need to install some prerequisite packages for the EV3 control packages to work. Start executing the following commands one by one.

```
$ sudo apt-get install ros-indigo-ros-control ros-indigo-ros-controllers
$ sudo apt-get install ros-indigo-joint-state-controller
$ sudo apt-get install ros-indigo-effort-controllers
$ sudo apt-get install ros-indigo-position-controllers
```

3. Now we need to source the generated source files.

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

Configuring EV3 Control Packages

4. First change to the source space directory of the catkin workspace

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

5. Now we need to download and extract the EV3 Control packages in the source space directory.

6. Now we need to build the packages in the catkin workspace:

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

Tutorial#4
ROS ⇔ EV3 Communication Setup

ROS ⇔ EV3 Communication over Network

In order to configure the communication between ROS and the EV3 we need to adjust the ROS enviroment variables on both sides (i.e. ROS and the EV3),

- ROS_MASTER_URI
- ROS_IP
- and ROS_HOSTNAME

First: Network Setup in ROS Side

1. First we need to know the IP adress of our PC. In a new terminal window write,

```
$ ifconfig
```

2. You should have some output like the following. Note your IP adress as we will need it in the following steps. In my case here 192.168.0.10.

```
viki@c3po:~/catkin_ws$ ifconfig
eth0      Link encap:Ethernet  HWaddr 08:00:27:af:de:fe
          inet addr:10.0.2.15  Bcast:10.0.2.255  Mask:255.255.255.0
          inet6 addr: fe80::a00:27ff:feaf:defe/64 Scope:Link
          UP BROADCAST RUNNING MULTICAST  MTU:1500  Metric:1
          RX packets:9253 errors:0 dropped:0 overruns:0 frame:0
          TX packets:1860 errors:0 dropped:0 overruns:0 carrier:0
          collisions:0 txqueuelen:1000
          RX bytes:12542111 (12.5 MB)  TX bytes:152253 (152.2 KB)

lo        Link encap:Local Loopback
          inet addr:127.0.0.1  Mask:255.0.0.0
          inet6 addr: ::1/128 Scope:Host
          UP LOOPBACK RUNNING  MTU:65536  Metric:1
          RX packets:228 errors:0 dropped:0 overruns:0 frame:0
          TX packets:228 errors:0 dropped:0 overruns:0 carrier:0
          collisions:0 txqueuelen:0
          RX bytes:23854 (23.8 KB)  TX bytes:23854 (23.8 KB)

viki@c3po:~/catkin_ws$
```

First: Network Setup in ROS Side

3. No we need to edit the ~/.bashrc file, and add the following lines to adjust Ros enviroment variables (i.e. ROS_MASTER_URI, ROS_IP, and ROS_HOSTNAME) for the network setup.
4. First change to the catkin workspace,

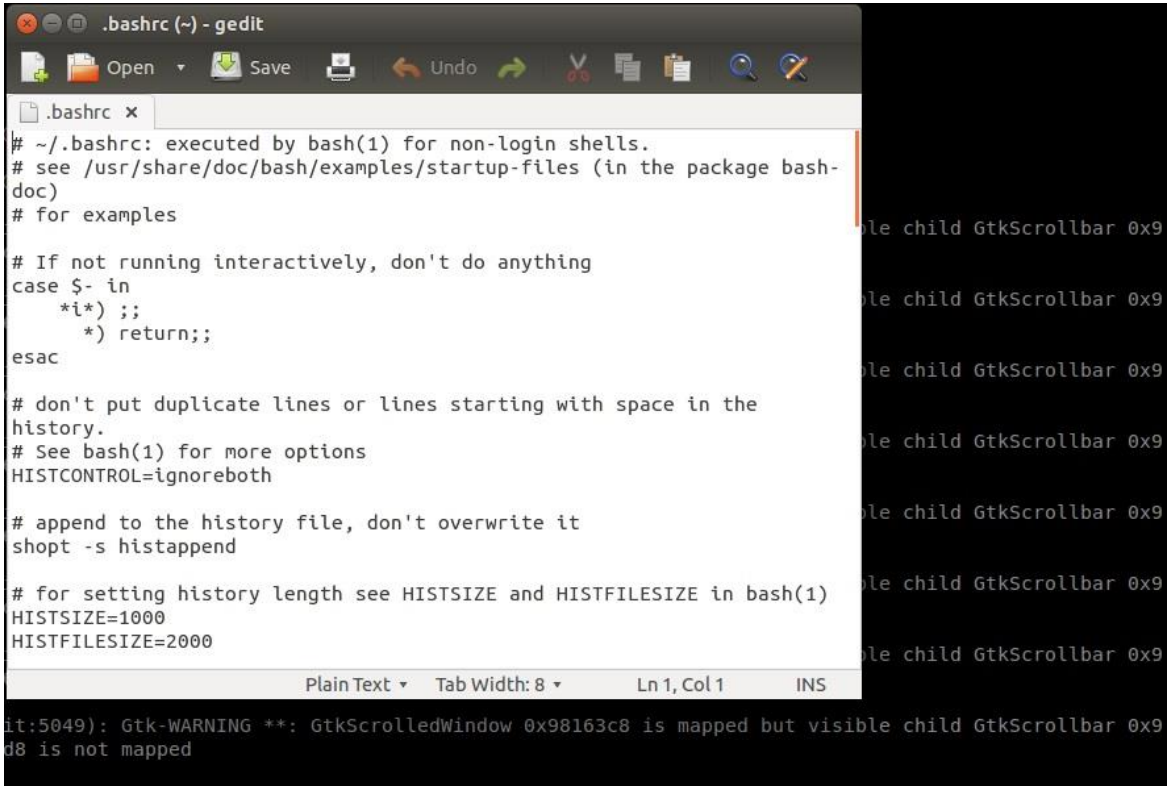
```
$ cd ~/catkin_ws
```

5. Now use the gedit command to edit the ~/.bashrc file

```
$ gedit ~/.bashrc
```

First: Network Setup in ROS Side

6. A text file should now open as it shown.



First: Network Setup in ROS Side

7. Since we are going to run our Ros master on our PC. Then we need to inform all robots in our ROS Network, that we will run our Ros master on our PC which has the IP adress 192.168.0.10 –we got this IP adress before from step2 -. In order to do that Programaticlly we need to add the following line at the end of the bash file.

```
> echo export ROS_MASTER_URI=http://192.168.0.10:11311 >> ~/.bashrc
```

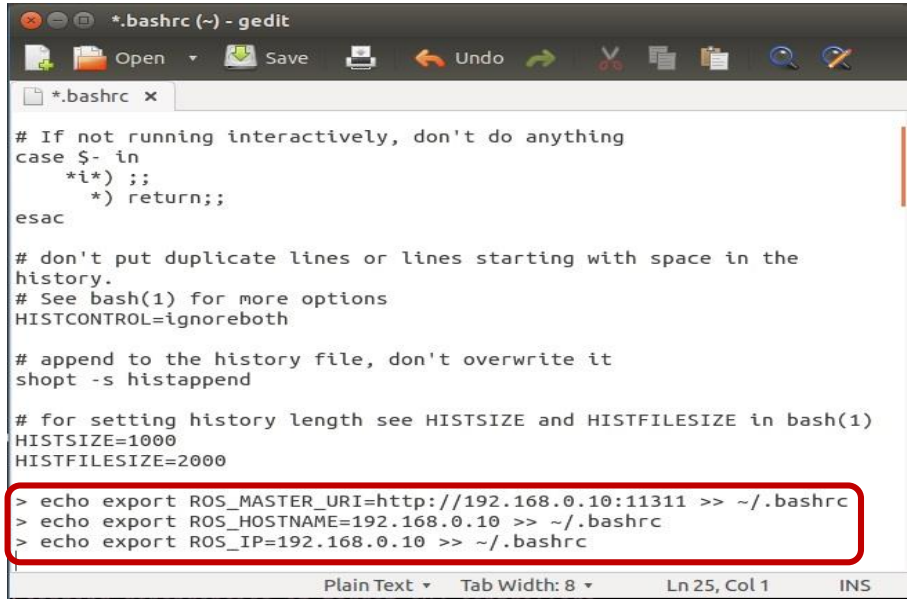
8. Now we need to identify the ROS_IP and ROS_HOSTNAME environment variables, in order to force ROS to use our PC IP address (i.e. 192.168.0.10) for all nodes generated on our PC.

First: Network Setup in ROS Side

9. In order to do that Programmatically we need to add the following two lines at the end of the bash file as well.

```
> echo export ROS_HOSTNAME=192.168.0.10 >> ~/.bashrc
> echo export ROS_IP=192.168.0.10 >> ~/.bashrc
```

10. Now you should have something like this. If so press save and close the ~/.bashrc file and all the opened terminals so all the changes can take place.



Second: Network Setup in EV3 Side

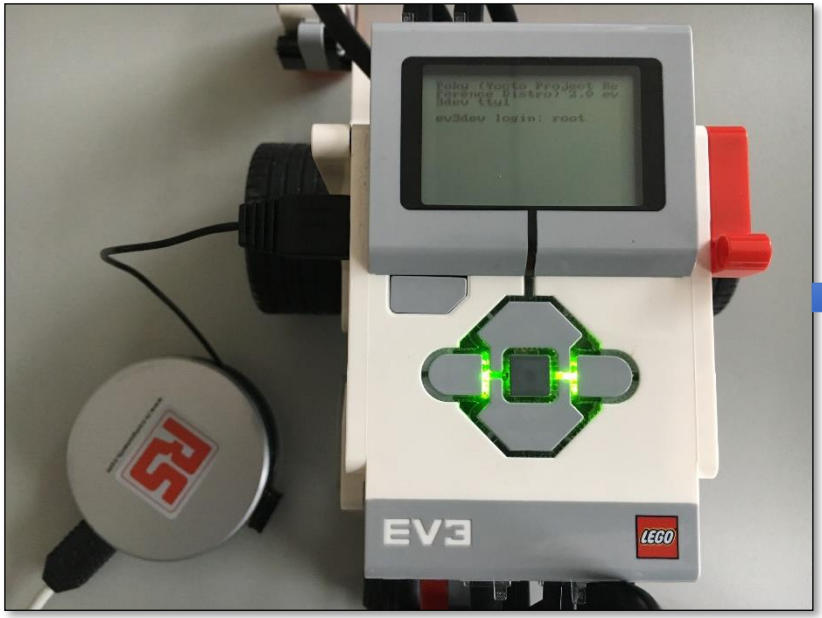
1. Insert the SD Card on the EV3.
2. Connect a keyboard and the EDIMAX Wifi nano USB adapter to the EV3 using a USB Hub.

Second: Network Setup in EV3 Side

3. Some seconds after starting you should see the H4R boot logo. After some time the yellow blinking LEDs should end and lighting up in a constant green.

Second: Network Setup in EV3 Side

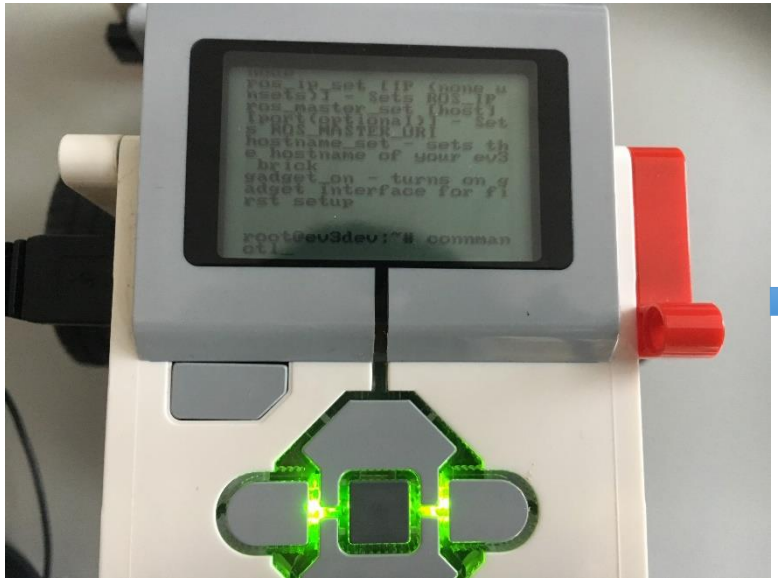
4. Now use the keyboard to enter the login password: root and press enter

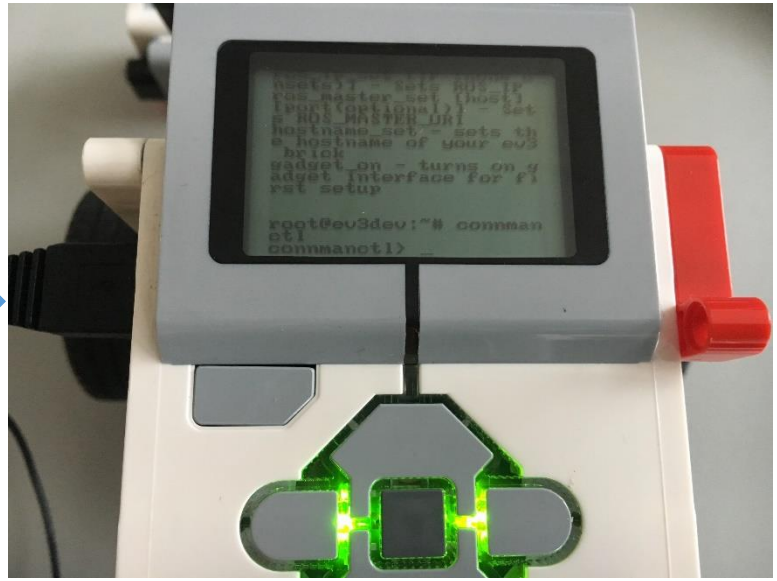


Second: Network Setup in EV3 Side

5. Now we need to configure our wifi network. To do that, write connmanctl which should give you a connman promt to configure our wifi network.

```
robot@ev3dev:~# connmanctl
```

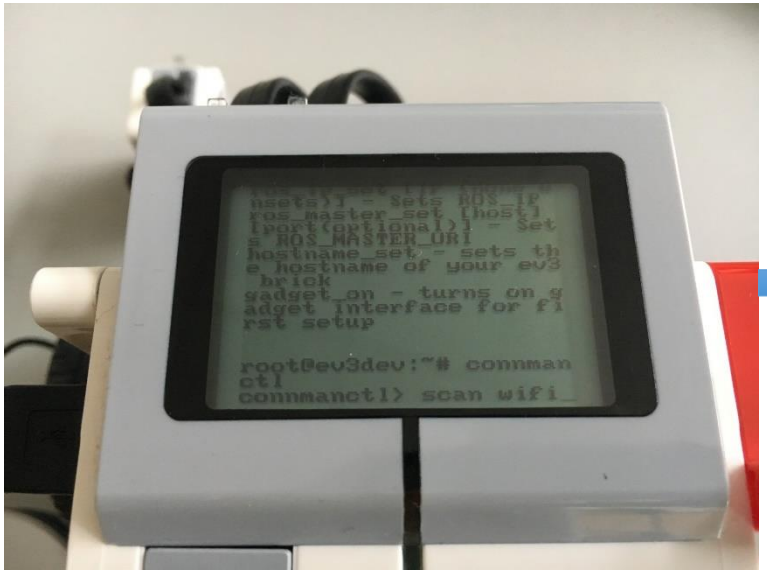


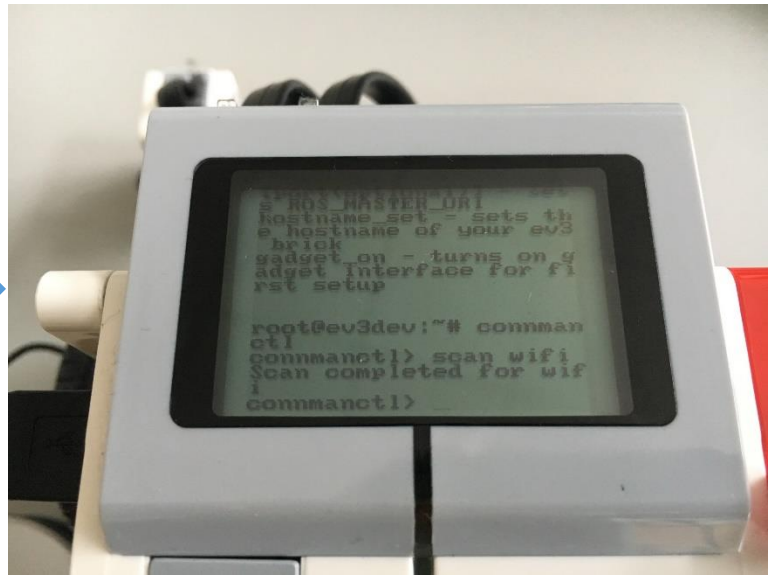


Second: Network Setup in EV3 Side

6. Now we need to Scan for access points (i.e. available wifi networks):

Connmanctl> scan wifi

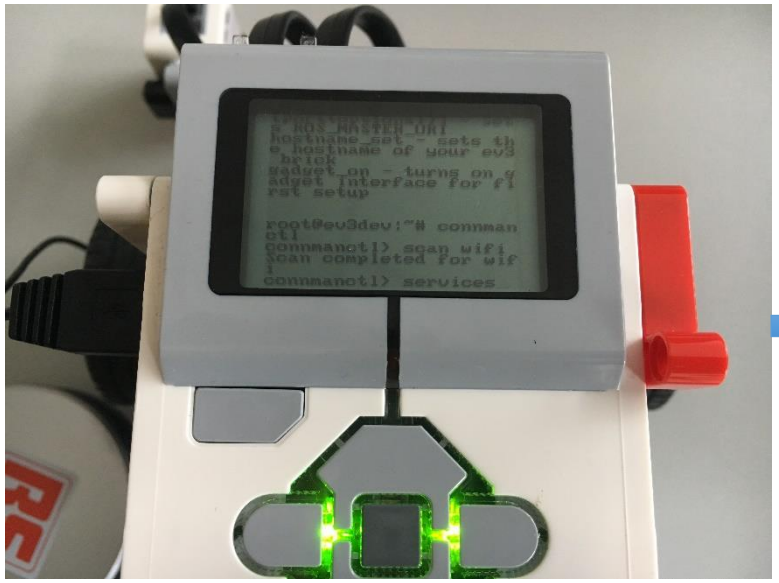


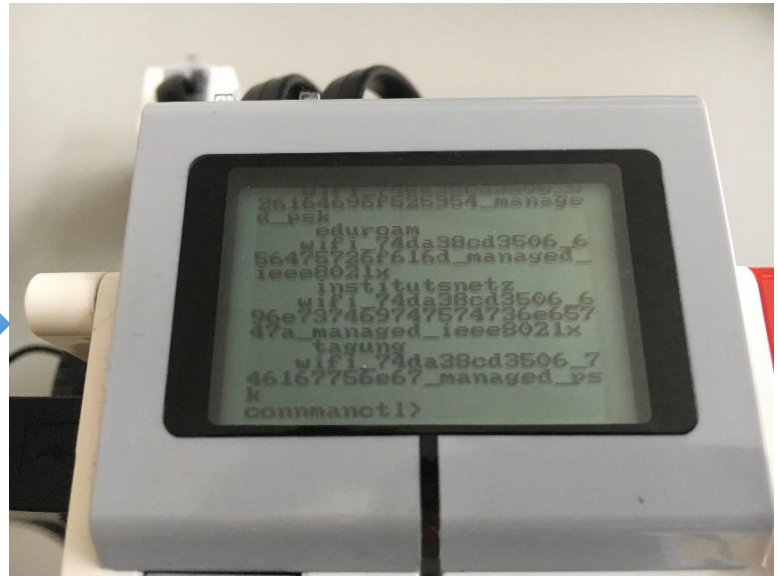


Second: Network Setup in EV3 Side

7. Then we need to display all discovered wifi networks. Take note of the network name, for example our wifi network is tagung and has a name “ wifi_74da38cd3506_746167756e67_managed_psk“

Connmanctl> services

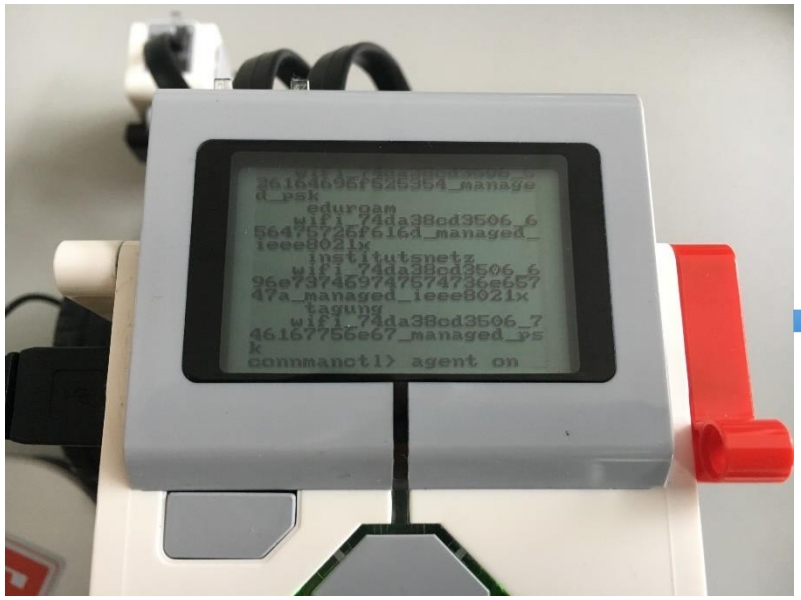


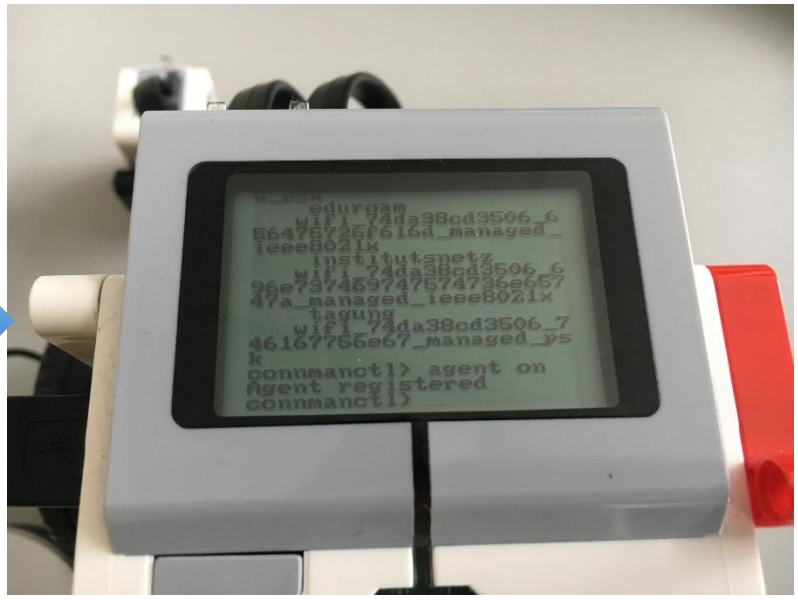


Second: Network Setup in EV3 Side

8. Then we need to register the agent to handle user requests. So we write agent on and press enter.

Connmanctl> agent on



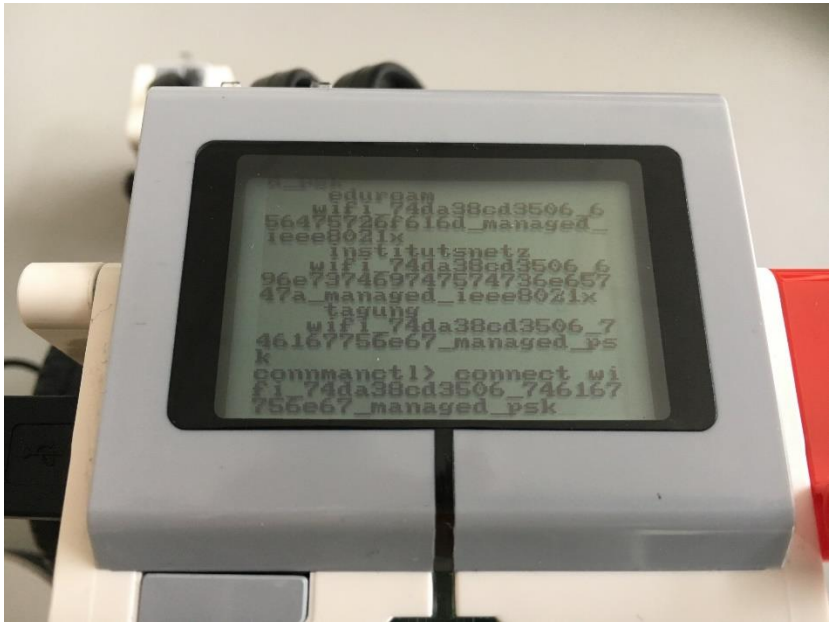


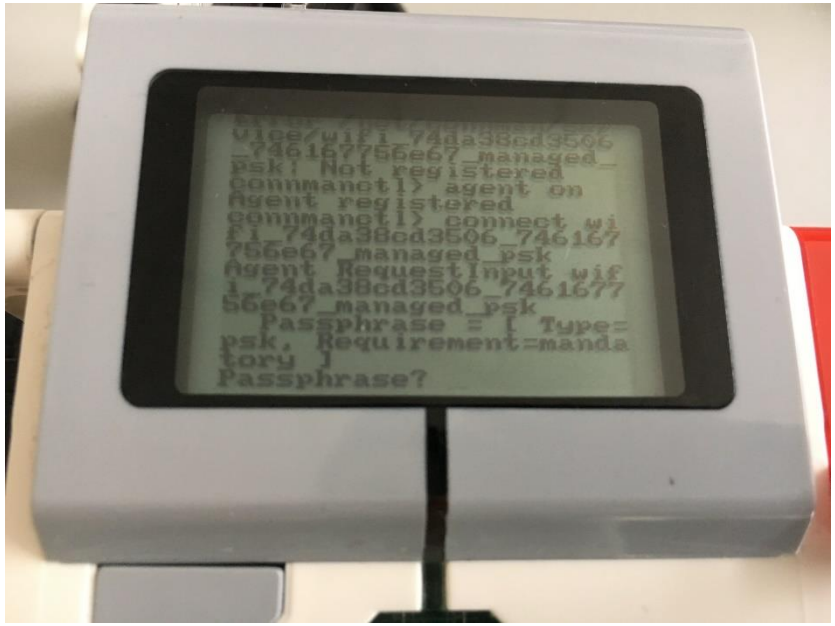
Second: Network Setup in EV3 Side

9. Connect to the tagung network using connect command and network name.

   Then enter the wifi password after ‘‘passphrase?‘‘.

Connmanctl> connect wifi_74da38cd3506_746167756e67_managed_psk





Second: Network Setup in EV3 Side

10. After we connect to the wifi network, we can now exit the Connmanctl by writing exit in order to go back to the main screen again.

```
Connmanctl> exit
```

Second: Network Setup in EV3 Side

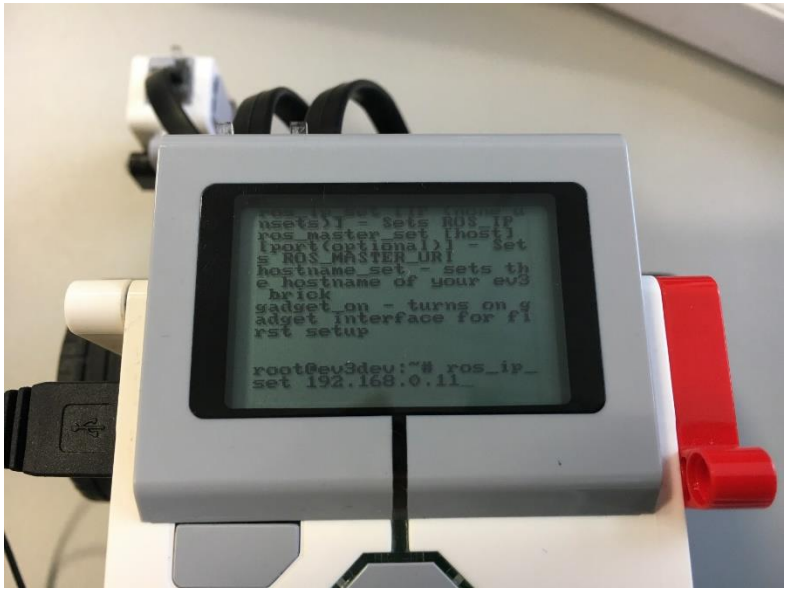
11. Now we need to adjust ROS environment variables one more time. Firstly we need to tell the EV3 robot that our ROS master will run on our PC which has the IP address 192.168.0.10. Use the keyboard to enter the following line to adjust the ROS_MASTER_URI variable.

ros_master_set 192.168.0.10:11311

Second: Network Setup in EV3 Side

12. Lastely we need to identify the ROS_IP environment variable to force ROS on the EV3 to use our EV3 IP address (i.e. 192.168.0.11) for all nodes generated on the EV3.

ros_ip_set 192.168.0.11



EV3 Reboot and Shutdown Commands

1. Reboot command

```
reboot
```

2. Shutting down

```
Shutdown –h now
```

Tutorial#5
ROS ⇔ EV3 Communication over Network

ROS ⇔ EV3 Communication over Network

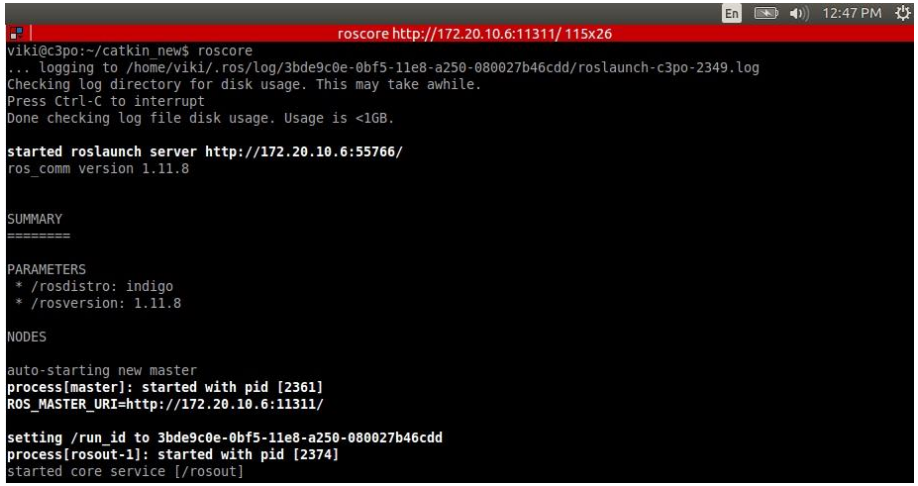
Once we finish our network setup, now we can establish the communication between the EV3 and ROS.

1. In a neu terminal on your PC change to the catkin workspace.

```
$ cd ~/catkin_ws
```

2. Open another new terminal on your PC and run roscore

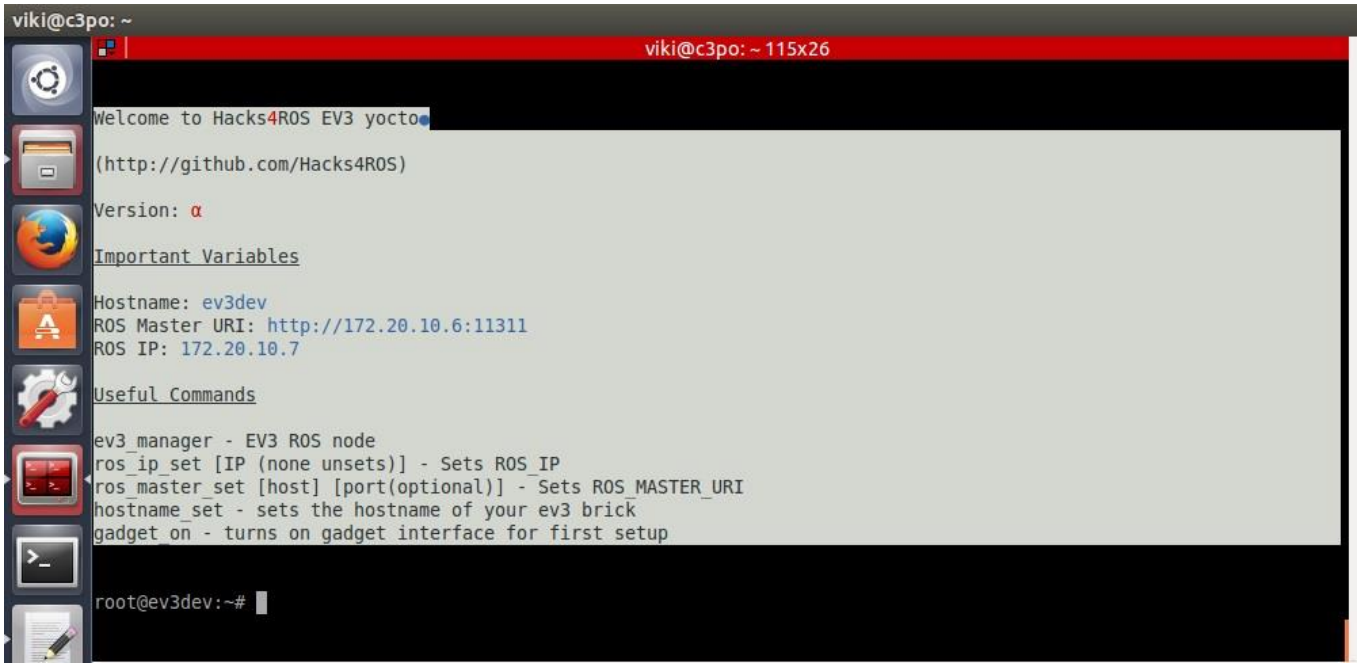
```
$ roscore
```



ROS ⇔ EV3 Communication over Network

3. In order to connect to our EV3, we need to connect via ssh by executing the following in another new terminal:

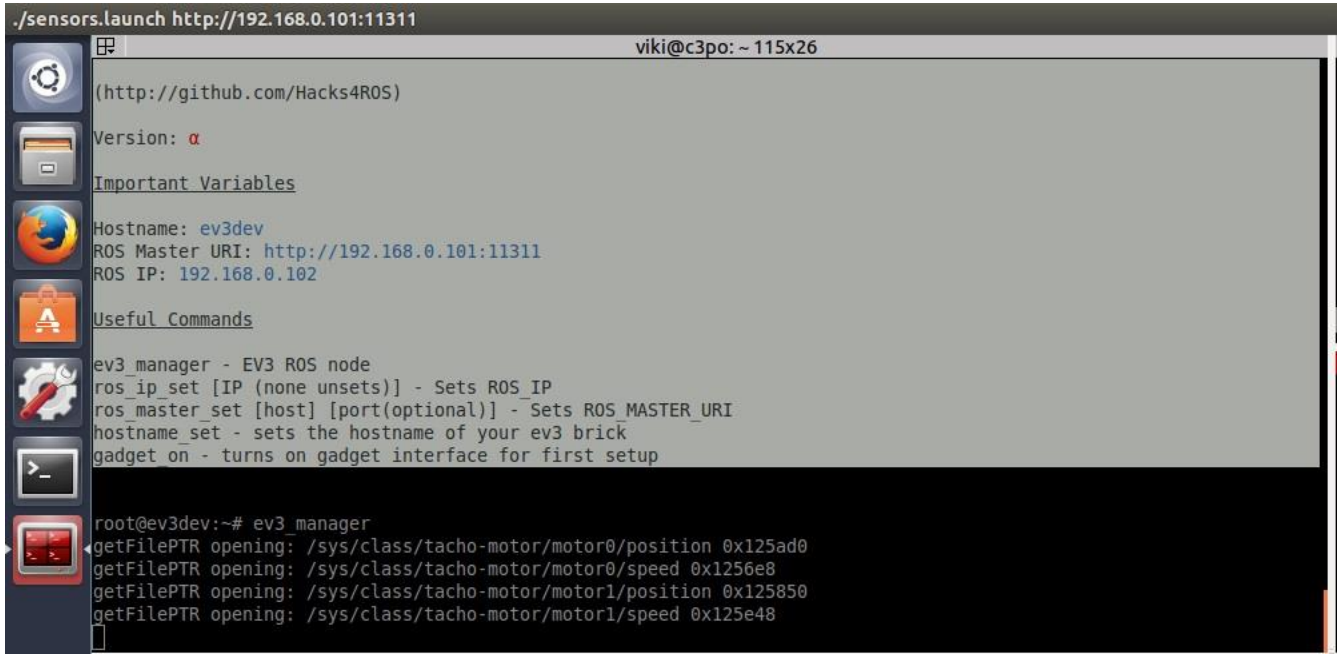
```
$ ssh root@192.168.0.11
```



ROS ⇔ EV3 Communication over Network

4. Once we are connected to our EV3 through the secured shell, write on the ssh the following and press enter

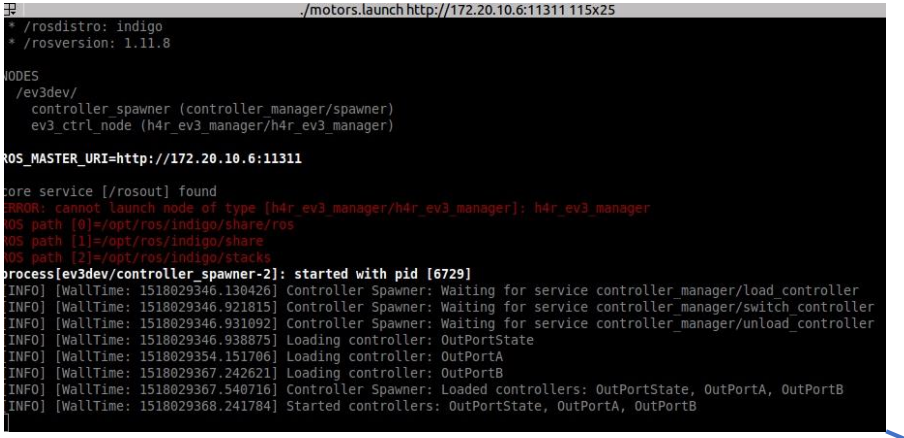
```
$ ev3_manager
```



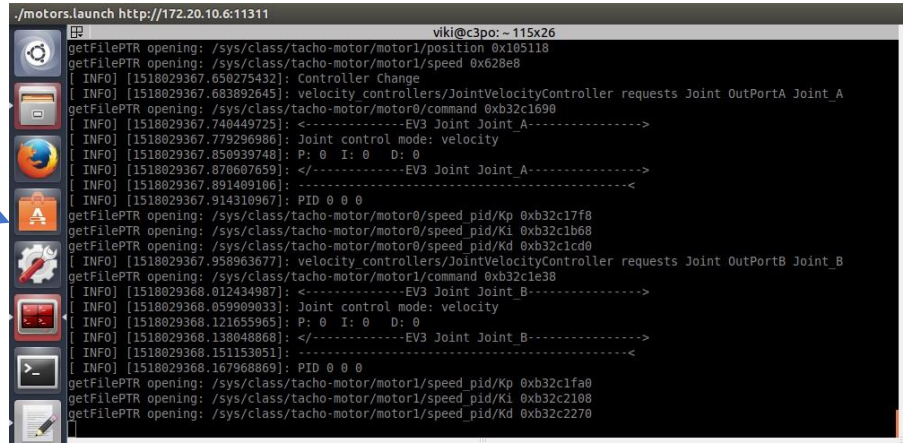
ROS ⇔ EV3 Communication over Network

5. Now we can launch our motors controllers, by executing the following in a new terminal

```
$ roslaunch ./motors.launch ev3_hostname:=ev3dev
```



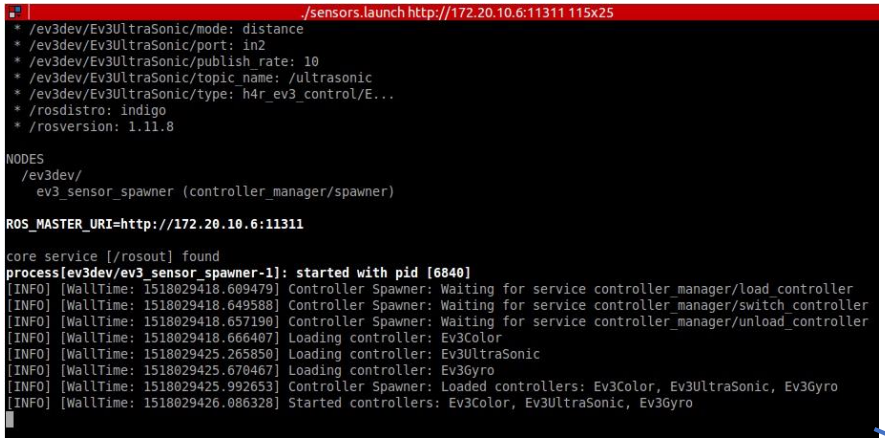
“Notice here also, the changes in the secured shell“



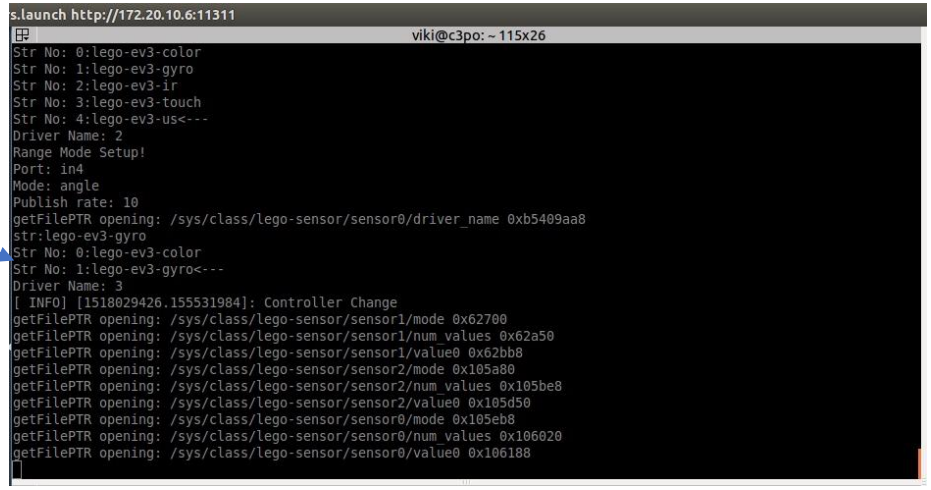
ROS ⇔ EV3 Communication over Network

6. Now we can launch our sensors as well, by executing the following in a new terminal

```
$ roslaunch ./sensors.launch ev3_hostname:=ev3dev
```



“Notice here also, the changes in the secured shell“



ROS ⇔ EV3 Communication over Network

7. Now we are ready to run our programs in a new terminal.

Tutorial#6:
Lego Mindstorms Ev3 Sensors

Lego Mindstorms Ev3 Sensors

Ev3 Color Sensor: The EV3 controller is used to read the standard EV3 Color Sensor. The mode parameter sets the mode for the color sensor. If not set, it will use **rgb_raw**. The following modes are possible for the sensor:

1. **rgb_raw:** 'rgb_raw' mode uses the RGB_RAW mode of this sensor. It will output the color information in RGB in a **std_msgs::ColorRGBA.msg** topic.
2. **Ambient**: 'ambient' mode measures the ambient light and publishes into a **sensor_msgs::Illuminance** topic
3. **Reflect:** 'reflect' mode measures the reflected light from an obstacle and publishes into a **sensor_msgs::Illuminance** topic

Lego Mindstorms Ev3 Sensors

4. **Color**: 'color' mode publishes the a number for the following recognized colors into a **std_msgs::UInt8** topic

Value	Color
0	none
1	black
2	blue
3	green
4	yellow
5	red
6	white
7	brown

Lego Mindstorms Ev3 Sensors

EV3 Ultrasonic Sensor: The Ev3 Ultrasonic Controller is used to read the standard EV3 Ultrasonic Sensor. The sensor has two modes,

1. **Distance:** publishes the measured distance into a **sensor_msgs::Range** topic.
2. **Listen:** publishes into a **std_msgs::Boolean** topic, when it detects another Ultrasonic Sensor or a loud noise (like a clap) the value is true otherwise false.
   - **max_range** sets the maximum range of values taken into account if a value is bigger it will be replaced by infinity. The maximum value for this parameter is 2.5 because the value 2.550 is the sensors error condition.
   - **min_range** sets the minimum range of values taken into account if a value is smaller it will be replaced by negative infinity.

Lego Mindstorms Ev3 Sensors

The Ev3 Gyro Sensor: The Ev3 Gyro Controller is used to read the standard EV3 Gyro Sensor. The mode parameter sets the mode for the gyro sensor. If not set, it will use **angle**. The sensor has three modes,

1. **Rate:** publishes the turn rate into a **sensor_msgs::Imu** topic (z-axis).
2. **Angle:** publishes the turn rate into a **sensor_msgs::Imu** topic (z-axis). Output values are in radian which has range in degrees (0 to 180° and 0 to -180°).
3. **rate&angle:** publishes both turn and angle into a **sensor_msgs::Imu** topic (z-axis).

References

1. Quigley, Morgan, et al. "ROS: an open-source Robot Operating System." ICRA workshop on open source software. Vol. 3. No. 3.2. 2009.
2. Quigley, M., Gerkey, B., & Smart, W. D. (2015). Programming Robots with ROS: a practical introduction to the Robot Operating System. " O'Reilly Media, Inc.".
3. https://www.automation.com/library/articles-white-papers/robotics/robotics-software-platforms-review
4. http://www.ros.org/history/
5. http://www.modulabs.co.kr/board_GDCH80/1562
6. http://wiki.ros.org/Distributions
7. http://wiki.ros.org/kinetic/Installation/Ubuntu

Questions

Thank You!