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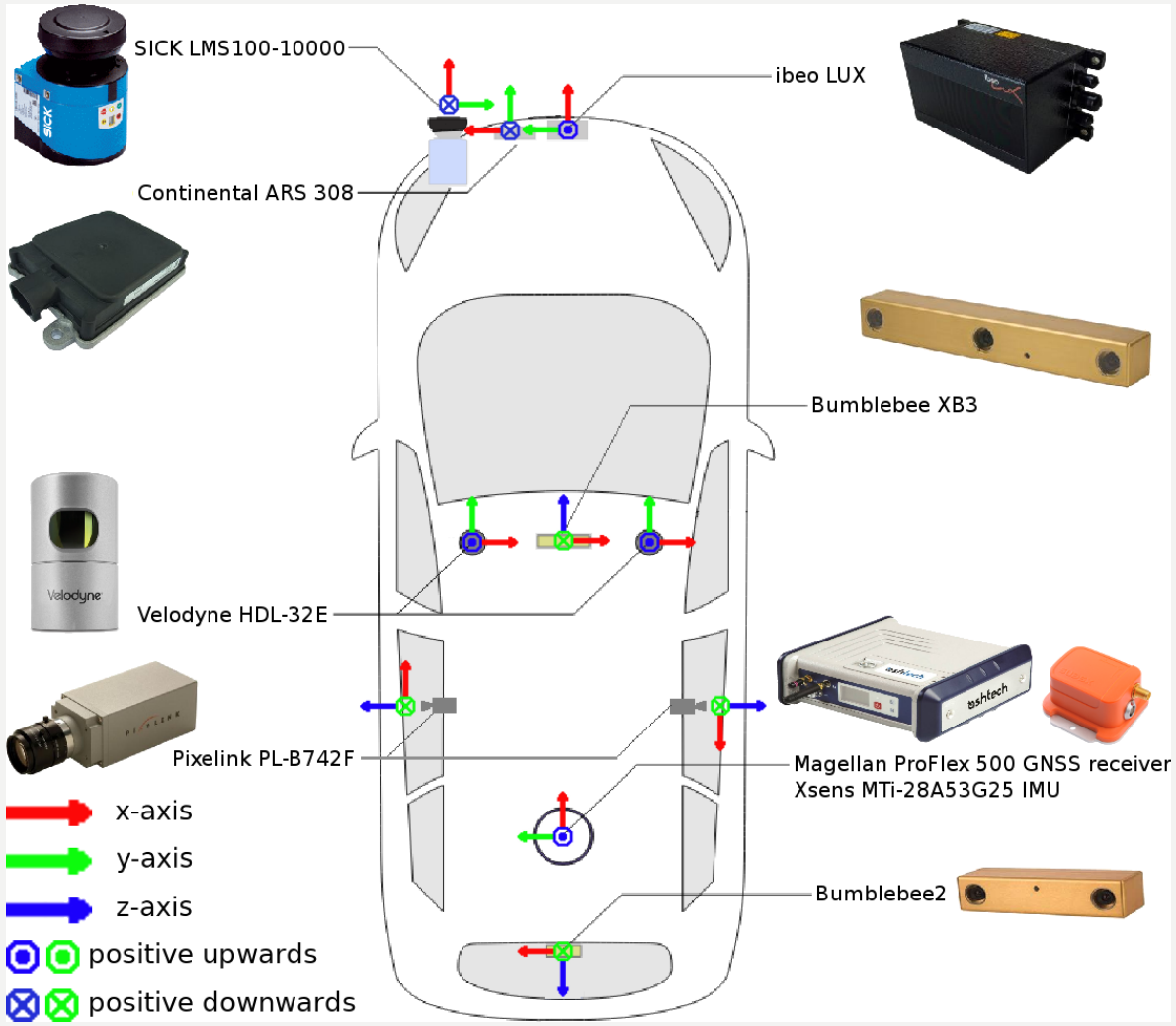
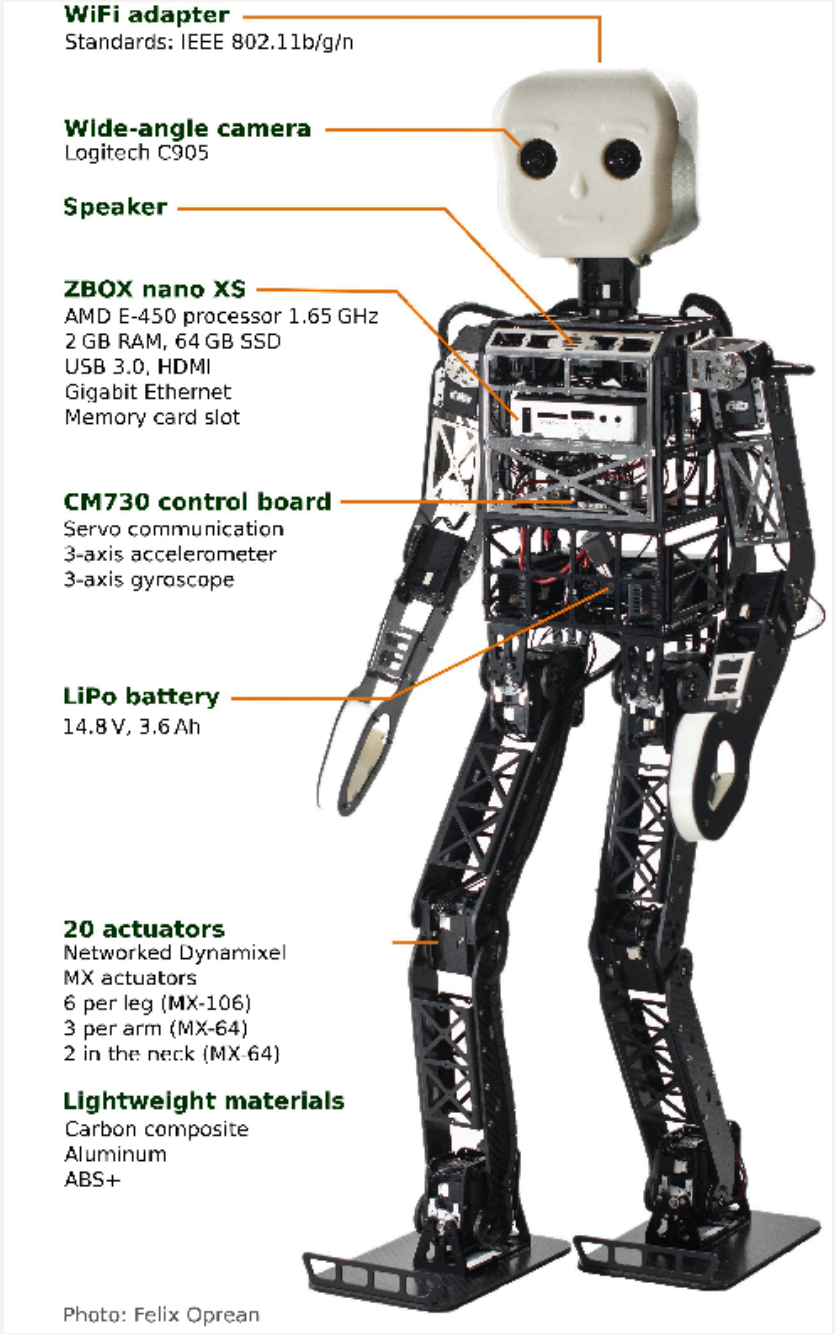
# COMPLEX SYSTEMS

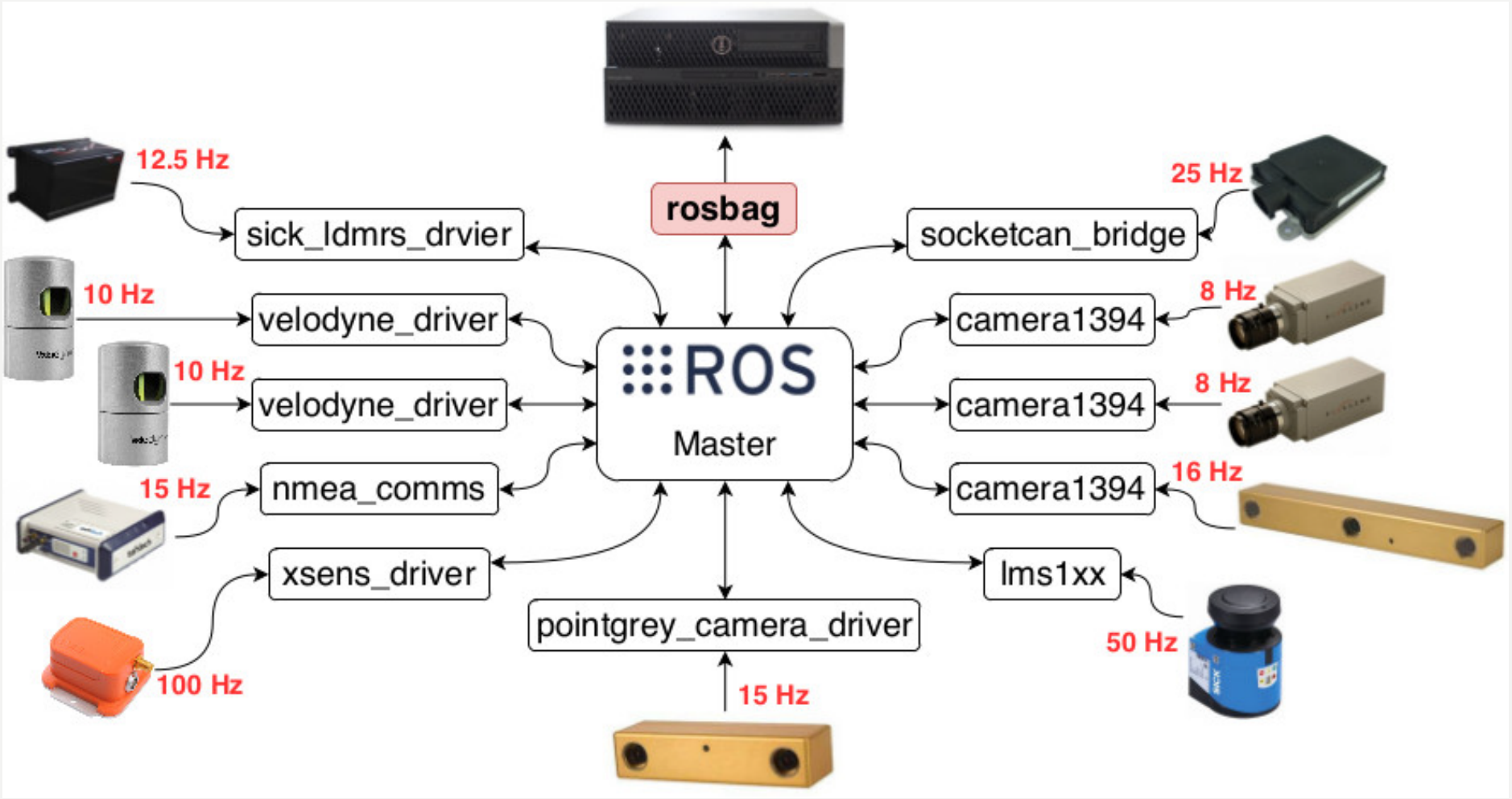



[Z. Yan, et al, "EU long-term dataset with multiple sensors for autonomous driving," 2020 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS). 2020.]




[M. Schwarz, et al, "NimbRo-OP humanoid teensize open platform," IEEE-RAS International Conference on Humanoid Robots, Osaka, 2012.]

# COMPLEX INTERACTIONS




[Z. Yan, et al, "EU long-term dataset with multiple sensors for autonomous driving," 2020 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS). 2020.]

# WHAT IS ROS

- **ROS: Tool**
  - Connects components
    - Sensors: Camera, IMU, Laser scanners …
    - Actuators: motors, linear actuators, …
    - Microcontrollers: Arduino, …
  - Main ROS Components:
    - *Nodes*
    - *Topics*
      - *Publish*
      - *Subscribe*

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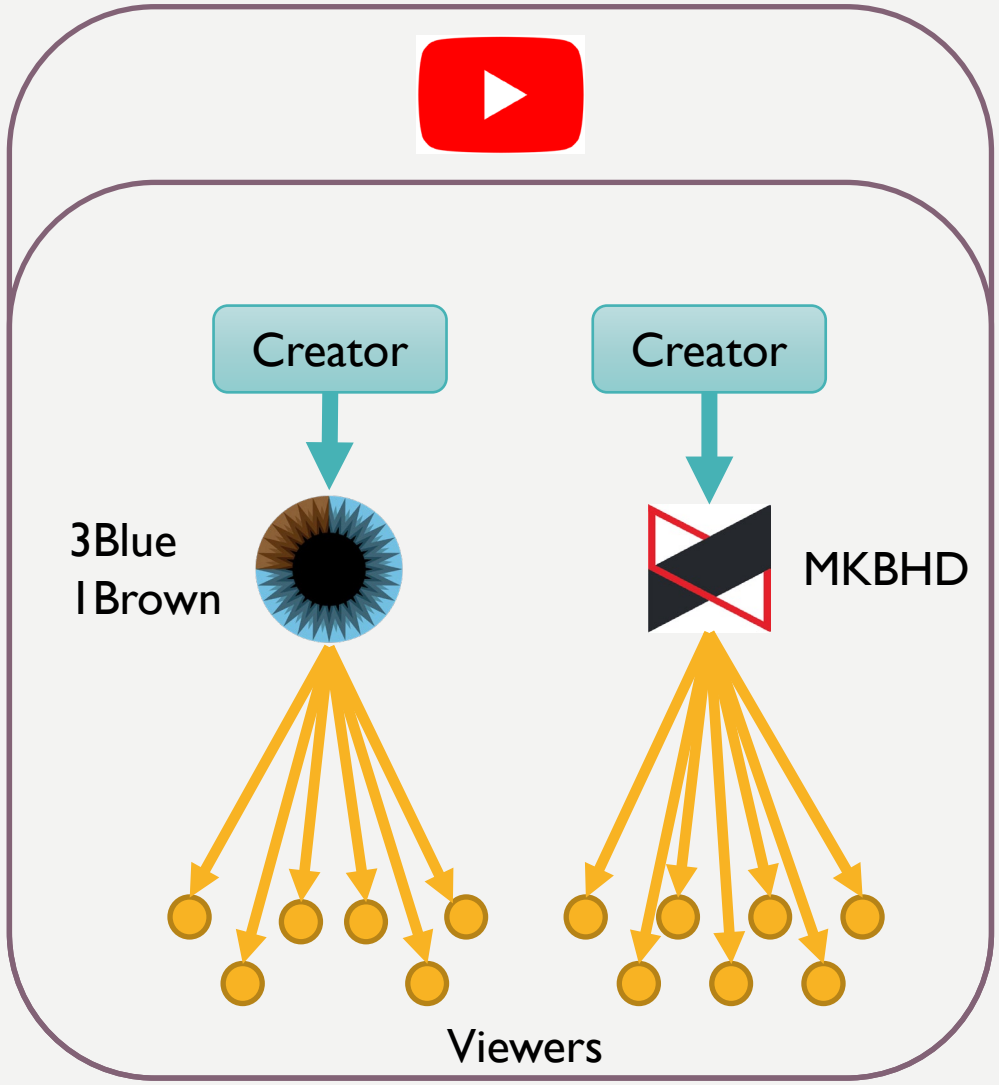
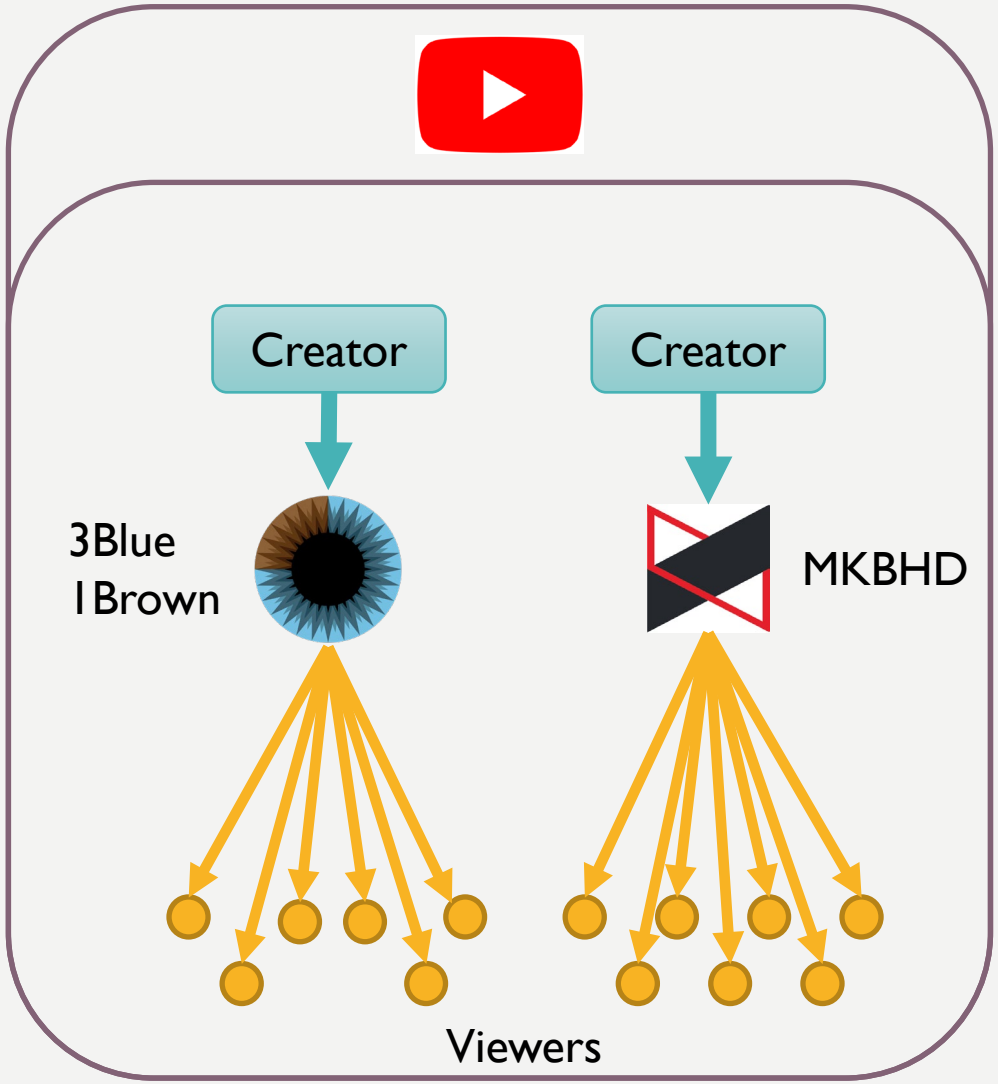
      - *Publish*
      - *Subscribe*
- **ROS: Community**
  - Many open-source software packages
    - Data processing: camera (OpenCV), lidar (PCL), …
    - Arm navigation (MoveIt)
    - Mapping and Localization (gmapping, amcl, …)
    - Simulation (Gazebo)
  - Forums
  - Tutorials
  - 600+ companies use ROS

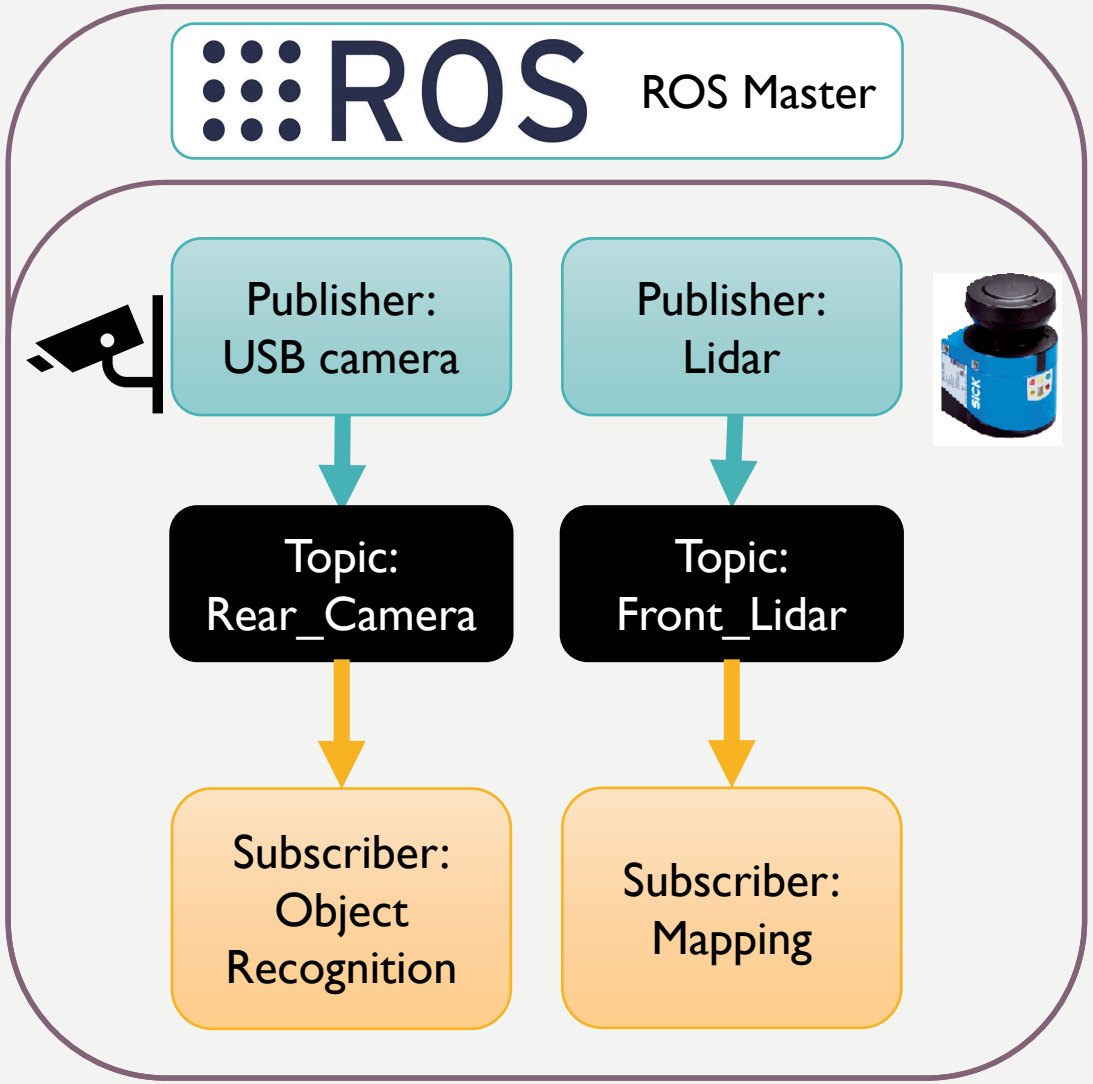
# PUB/SUB MODEL: ANALOGY




- YouTube:
  - Channels provide content
  - Creators ***publish*** content
    - regardless of viewership
  - Viewers ***subscribe*** to the channel
    - regardless of videos being published
- Topic = Channel
- Publish = send data to topic
- Subscribe = receive/wait for data from a topic

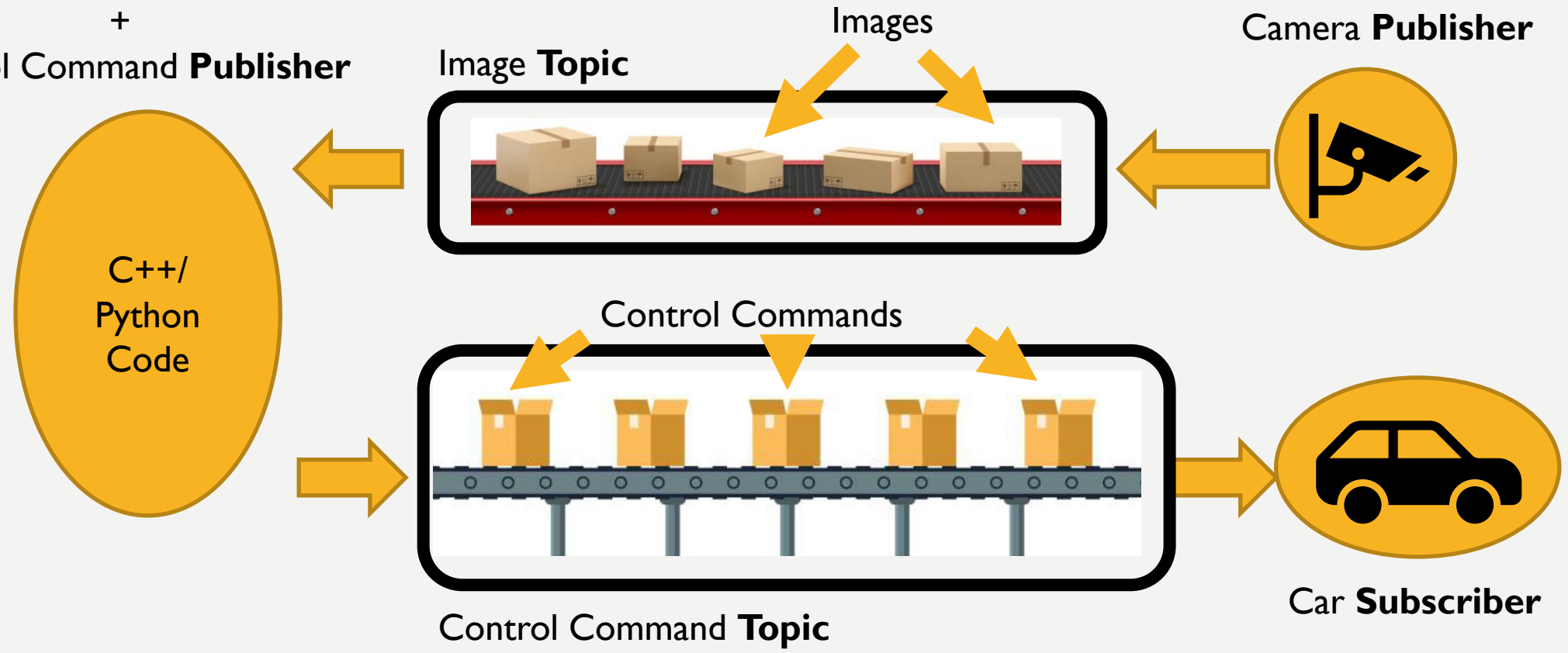
# PUB/SUB MODEL



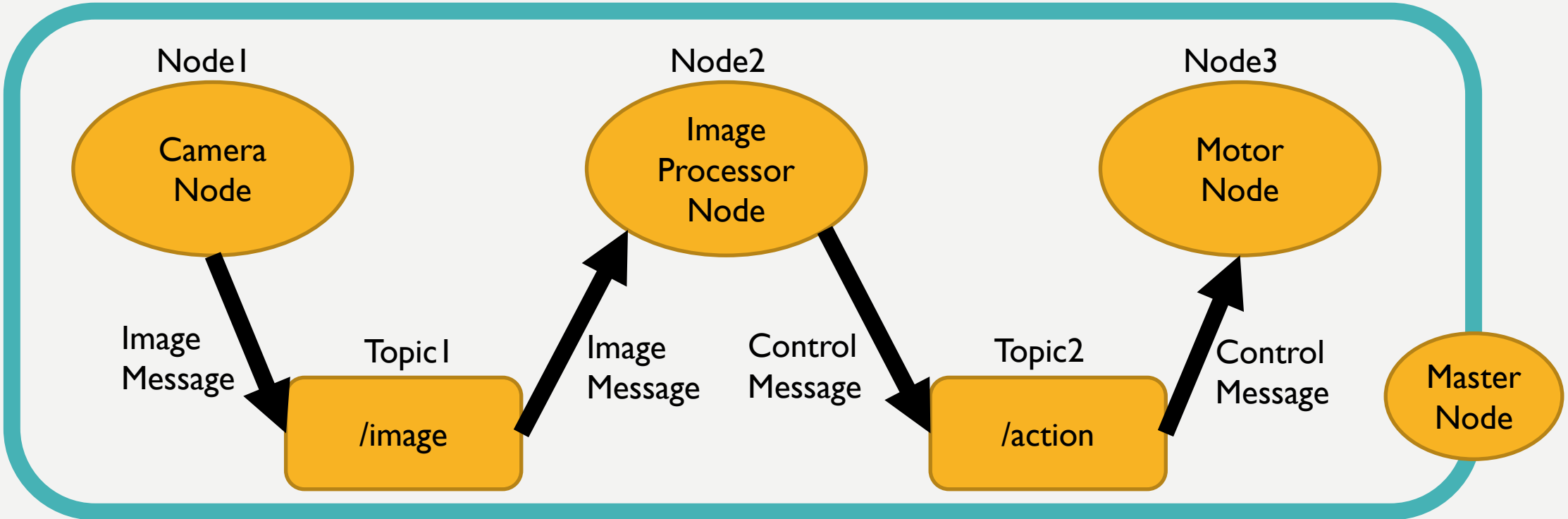
# EXAMPLE

Image **Subscriber**
+
Processing code
+
Control Command **Publisher**



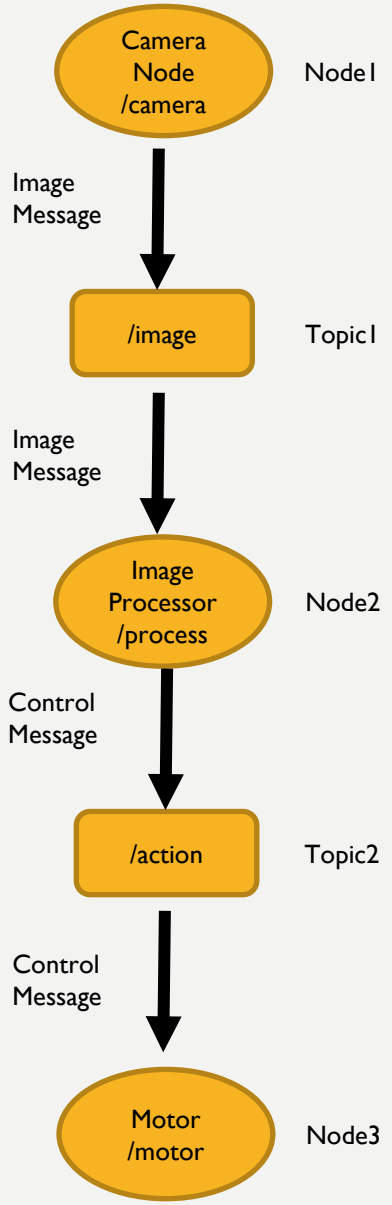
# NODES, TOPICS, MESSAGES

- Node: Processing unit – does some computation (Typically C++ or Python)
- Nodes talk over Topics
  - Send (publish) messages, Receive (subscribe) message, or Both



# ROS TOOLS: NODES, TOPICS, MESSAGES

- rosnode (require master)
  - `rosnode list`: lists all nodes
  - `rosnode info <node>`: gives information about a node
- rostopic (require master)
  - `rostopic list`: lists all topics
  - `rostopic info <topic>`: gives information about the topic
  - `rostopic echo <topic>`: displays the data through a topic
  - `rostopic hz <topic>`: finds the frequency of publishing to a topic
- rosmsg
  - `rosmsg list`: lists all messages
  - `rosmsg show <msgType>`: display message type details

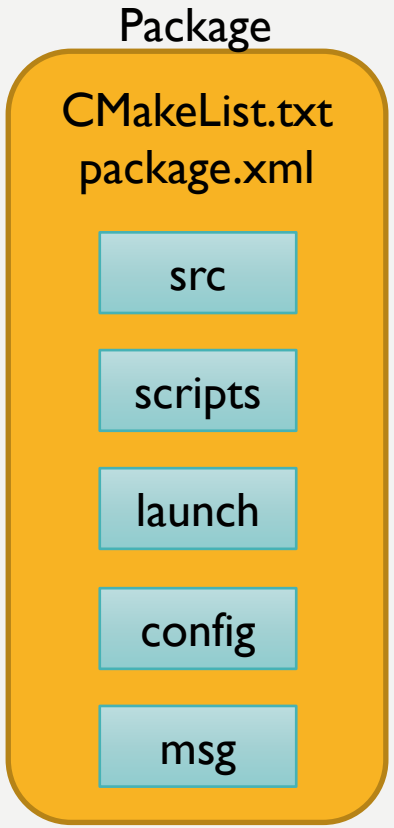


# USING ROS

- ROS is *thin*: Integrates into code
- Integration in C++/Python
    1. Create a script (C++, Python, …)
    2. Import the ROS library (roscpp for C++, rospy for Python, …)
    3. Define a node
        - e.g. in Python: rospy.init_node(‘process’)
    4. Define publishers or subscribers (or both)
        - e.g. in Python: pub = rospy.Publisher('/action', control_msg)
    5. Publish or subscribe
        - e.g. in Python: pub.publish(data)
- Run the script with rosrun
    - e.g. rosrun image_package process_image.py

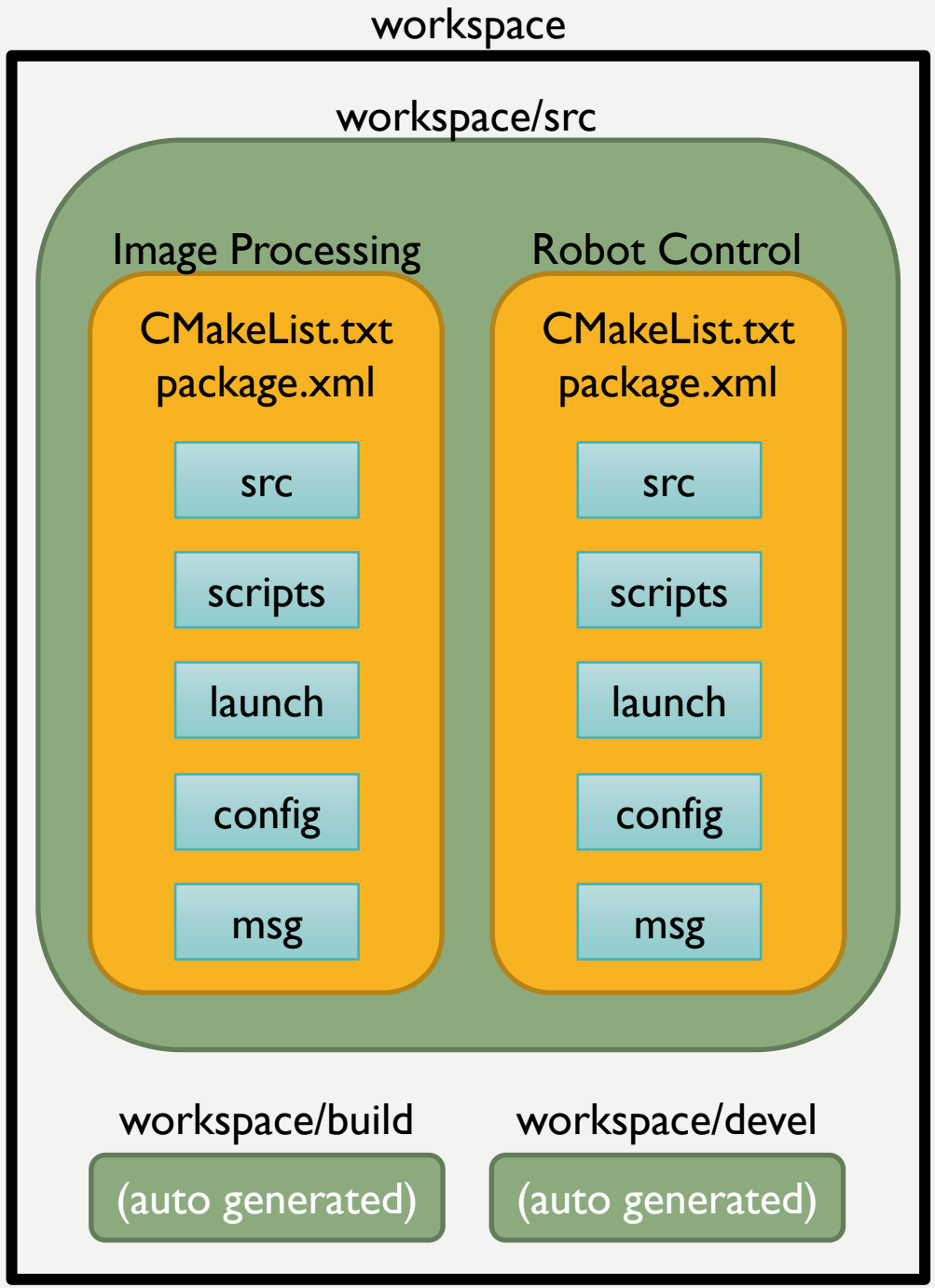
# ROS PACKAGE

- **Package**
  - **CMakeLists.txt (defines dependencies and requirements)**
  - **package.xml (defines package name, dependencies, …)**
  - **src (files that define nodes (.cpp, .py))**
  - scripts (files that don't define nodes)
  - launch (.launch files to automatically run many nodes)
  - config (YAML files with parameters for users to edit)
  - msg (contains custom message definitions: .msg files)
- Examples:
  - Image processing package: process images in different ways
  - Mapping package: generate a map of the environment
  - Planning package: plan the robot path



# CATKIN

- We have many components:
  - C++ files
  - Python scripts
  - Custom Messages
  - Multiple packages
- What to do?
- **Catkin Workspace:** directory for all ROS development
- **catkin_make:** tool that helps compile and link all the different components



# WORKSPACE OVERVIEW

- **workspace** (use catkin_make in this directory)
  - *build* (auto generated)
  - *devel* (auto generated)
    - `setup.bash` (source this so ROS can "see" all files: `source workspace/devel/setup.bash`))
  - **src** (all the code you write is here)
    - **ImageProcessingPackage**
      - CMakeLists.txt, package.xml
      - src
        - detect_people.py, find_traffic_signs.cpp, ...
    - **MappingPackage**
      - CMakeLists.txt, package.xml
      - src
    - **ControlPackage**
      - CMakeLists.txt, package.xml
      - src

# ROSRUN & ROSLAUNCH

The code is written.

The package is built.

How do you run the code with ROS?

# ROSRUN & ROSLAUNCH

- rosrun
  - Starts a single node
  1. Start the ROS master (if not already started)
     - run in a terminal: `roscore`
  2. Start the file
     - `rosrun <package_name> <node_name>.<cpp, py, …>`

# ROSRUN & ROSLAUNCH

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     - `rosrun <package_name> <node_name>.<cpp, py, …>`

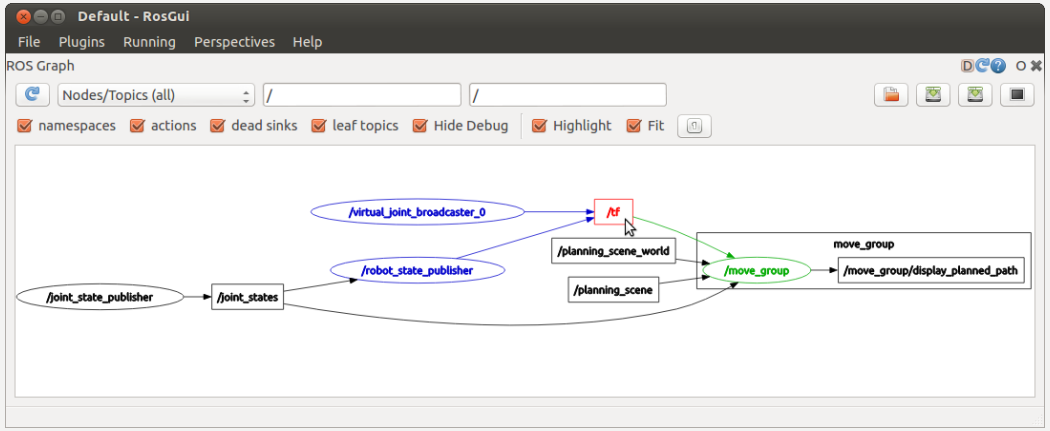
- roslaunch
  - Starts many nodes, possibly with certain parameters, and starts the master (if needed)
  1. Write a .launch script with all nodes
  2. Start the script
     - `roslaunch <package_name> <launch_file_name>.launch`

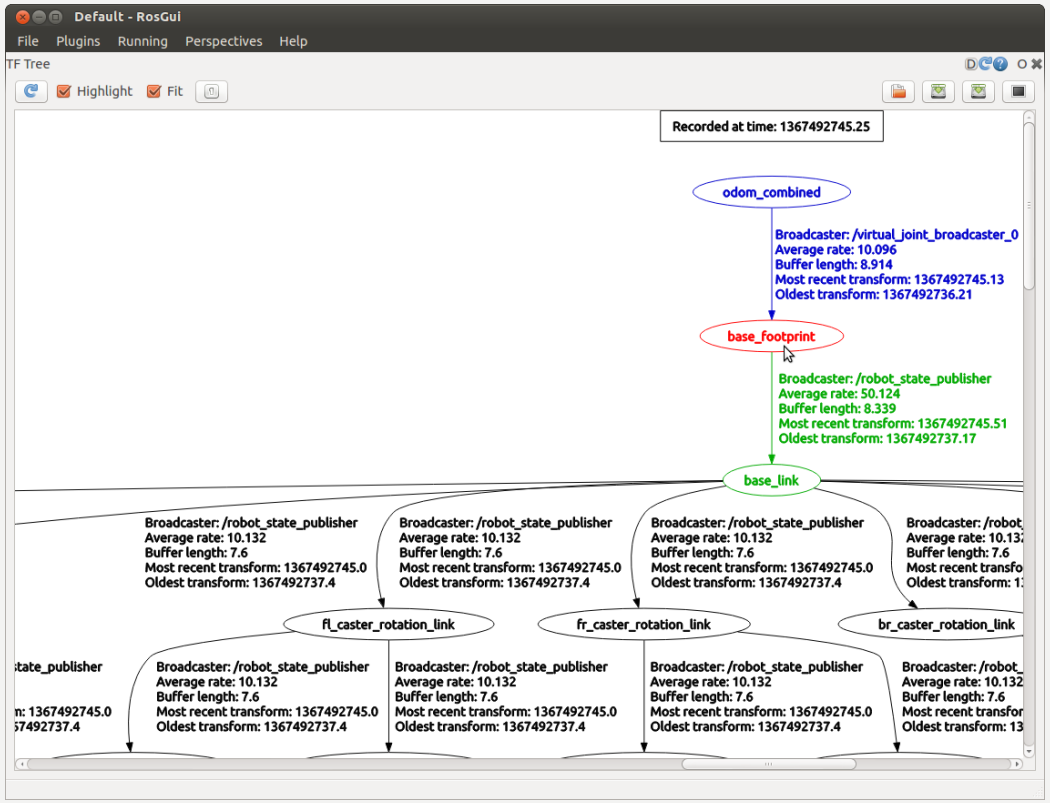
# PARAMETER SERVER

- Parameters needed (across many scripts)
- ROS parameter server
  - Tracks all parameters
  - Managed by ROS master
  - Any node can get and set a parameter value
    - Running nodes not affected
  - Examples
    - /move_base/local_costmap/height
    - /usb_cam/framerate
    - /gazebo/time_step

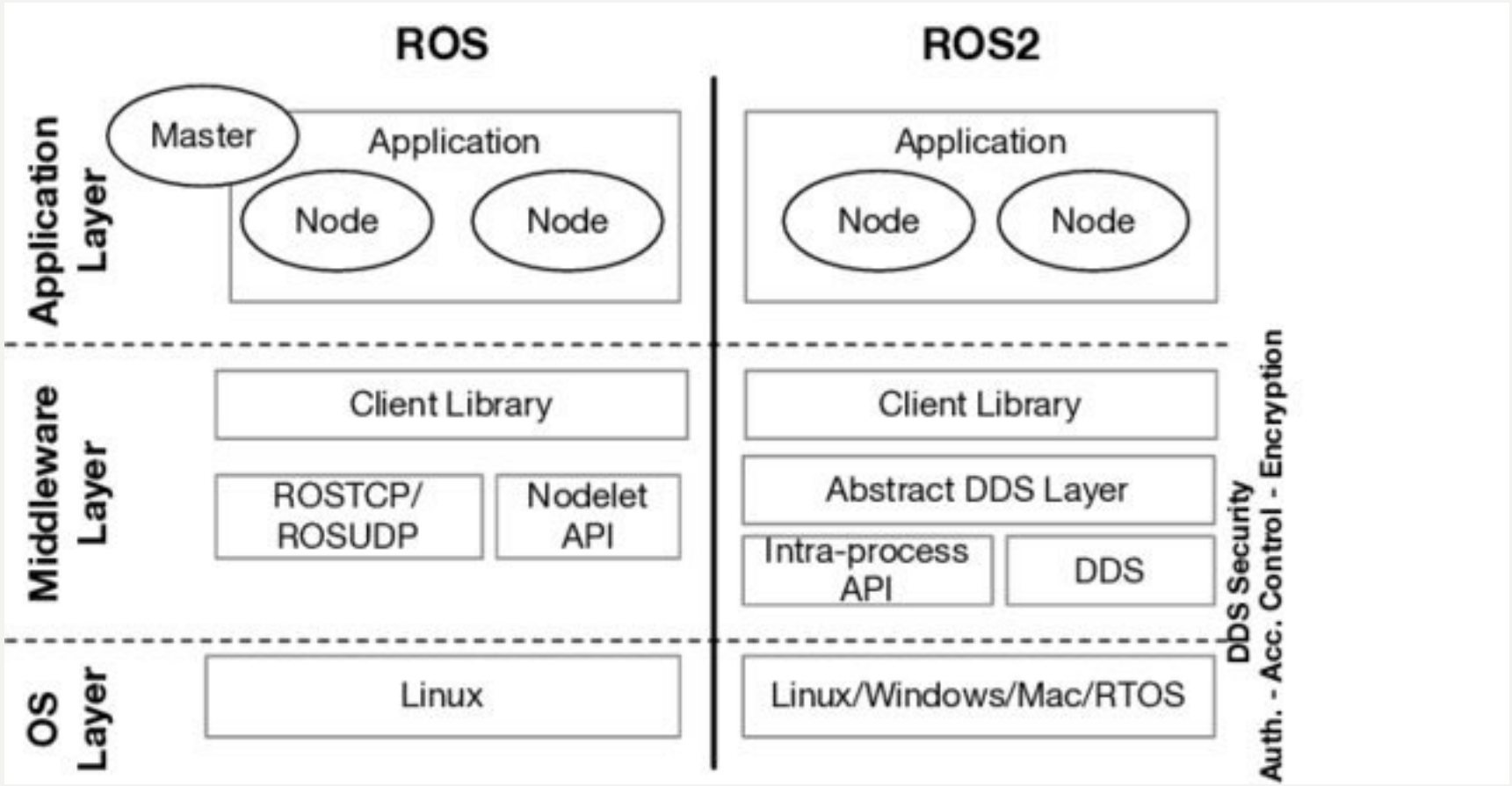
# DEBUGGING

- Many ROS tools
  - `rqt_console`
  - `rqt_graph`
  - `rqt_tf_tree`
  - `rosbag`
    - `rosbag record <topic>`
    - `rosbag play file.bag`
  - `rospy.loginfo()`



# ROS1 AND ROS2




[G. Mazzeo and S. Mariacarla, "TROS: Protecting Humanoids ROS from Privileged Attackers, " International Journal of Social Robotics, Vol. 12, pp 827-841, 2020.]

ROS is more mature than ROS2
Final ROS distro: Noetic (2020)

ROS2 distros:
Foxy (2020), Humble (2022)

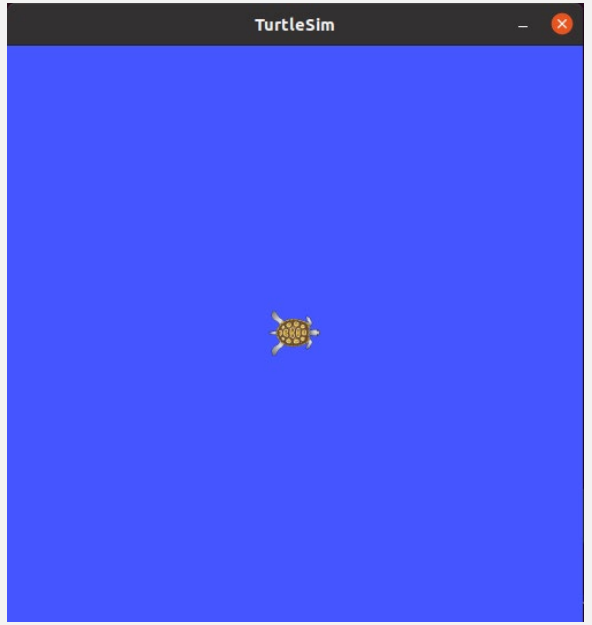
# SUBMITTED QUESTIONS

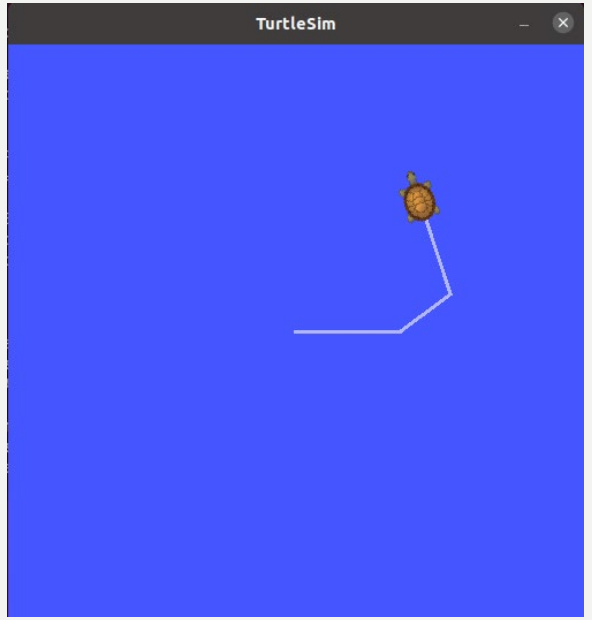
- Robots and microcontrollers
  - Arduino boards are common
  - Interface with them via rosserial package
- Integrating multiple sensors
  - Publish sensor data to various topics
  - Write scripts to subscribe, process the data, and publish processed info
  - Write a script to subscribe to the processed data and do something
- Robotic Prosthetics
  - Humanoid robots (e.g. PR2 robot), robot manipulators, ... very common
  - Shadow Robot (prosthetics company) uses ROS
- Component control
  - Many ROS tools allow you to design the controller then interface with an actuator (e.g. via an Arduino or ESC)

# DEMO

# TURTLESIM DEMO

- Turtlesim is a package that comes preinstalled with the ROS full installation.
- Package name: `turtlesim`
- Some ROS nodes:
  - `turtlesim_node:` starts a turtle simulator
  - `turtle_teleop_key:` moves the turtle using the keyboard arrow keys



# TURTLESIM DEMO

- All text in `code-font` should be executed in a terminal.
- If a terminal window is in-use, open another terminal window.
- Start roscore (new terminal)
  - `roscore`
- Start the turtlesim node (new terminal)
  - `rosrun turtlesim turtlesim_node`
- See nodes and topics (new terminal)
  - `rosnode list`
  - `rostopic list`
  - `rqt_graph`

```
demo@demo:~$ rosnode list
/rosout
/turtlesim
demo@demo:~$ rostopic list
/rosout
/rosout_agg
/turtle1/cmd_vel
/turtle1/color_sensor
/turtle1/pose
```

# TURTLESIM DEMO

- Start the teleoperator node (new terminal)
  - `rosrun turtlesim turtle_teleop_key`
- See nodes and topics (in a new terminal)
  - `rosnode list`
  - `rostopic list`
  - `rqt_graph`
  - `rostopic echo /turtle1/cmd_vel`

```
demo@demo:~$ rosnode list
/rosout
/teleop_turtle
/turtlesim
demo@demo:~$ rostopic list
/rosout
/rosout_agg
/turtle1/cmd_vel
/turtle1/color_sensor
/turtle1/pose
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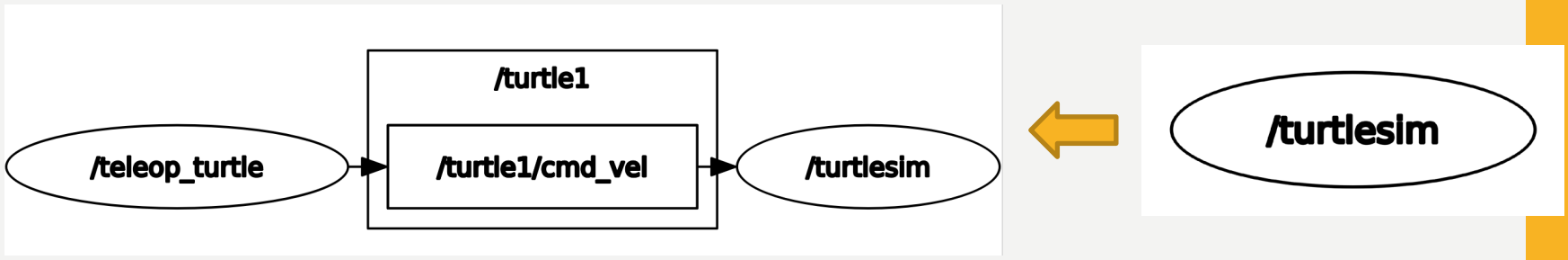

# TUTORIAL: CREATE WORKSPACE

- Creating a catkin workspace:
  - `cd  # goes to the home directory (~)`
  - `mkdir –p workspace/src  # creates (~/workspace/src)`
  - `cd workspace # goes to ~/workspace`
  - `catkin_make  # builds the ROS workspace`
- You should now have `build, devel` folders in `workspace`
- Source your workspace (every time you start a new terminal)
  - `source ~/workspace/devel/setup.bash`

# TUTORIAL: CREATE PACKAGE

- You can create a package manually or using `catkin_create_package`
  - `cd ~/workspace/src  # go to ~/workspace/src, all packages go here`
  - `catkin_create_package demo_package std_msgs rospy`
- You now have an empty package called `demo_package` with dependencies `std_msgs, rospy`
- Build the workspace
  - `cd ~/workspace`
  - `catkin_make  # compiles the ROS workspace`

# TUTORIAL: CREATE A NODE

- Go to the package `src` folder (`~/workspace/src/demo_package/src`) and create a script. Let's call it `publisher_node.py`
- Add code.
- This is a python script, so
  - we need to make it an executable: `chmod +x publisher_node.py`
  - we do not need to rerun `catkin_make`
- Start the ROS master
  - `roscore`
- Run the script
  - `rosrun demo_package publisher_node.py`
- Analyze the script
  - E.g. `rostopic echo \counter`

# TUTORIAL: MULTIPLE PACKAGES

- In `workspace2`, two packages are provided:
  - `data_publisher`: mimics a sensor publishing distance data and the associated confidence (probability) with the distance
  - `data_analyzer`: subscribes to the distance and probability data, analyzes them, and publishes a message about the safety status (safe, distance too small, low confidence)

- Run the two scripts `publisher_node.py` and `safet_based_on_data.py` and analyze what is going on using `rostopic list`, `rostopic echo <topic name>`, `rqt_graph`, `...`
  - Hint 1: Review the slide on `rosrun` slide (slide 16)
  - Hint 2: Review how we used `rosrun` in previous slides
  - Hint 3: See next slide for commands

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  - Run `rosrun data_publisher publisher_node.py`
  - Run (new terminal) `rosrun data_analyzer safet_based_on_data.py`
  - Run (new terminal) `rostopic echo \data`
  - Run (new terminal) `rostopic echo \decision`

# DEBUGGING TIPS

- Python not finding ROS package (e.g. when importing custom messages)
  - Make sure the package has been compiled
  - Make sure your custom message is defined properly in `CMakeLists.txt`
  - Make sure message generation and message runtime dependencies are defined in `CMakeLists.txt` and `package.xml`
  - Make sure your `workspace/devel/setup.bash` is sourced
  - Make sure ROS master is running
- `rostopic echo <topic>` throws `ERROR: Cannot load message class for [<message_type>]. Are your messages built?`
  - Make sure your `workspace/devel/setup.bash` is sourced
  - Make sure ROS master is running
  - Make sure your message shows up using `rosmsg show`
- Check forums, ROS wiki, or Google the errors