MODULE 2: ROBOT OPERATING SYSTEM

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Robots within HRI Topic

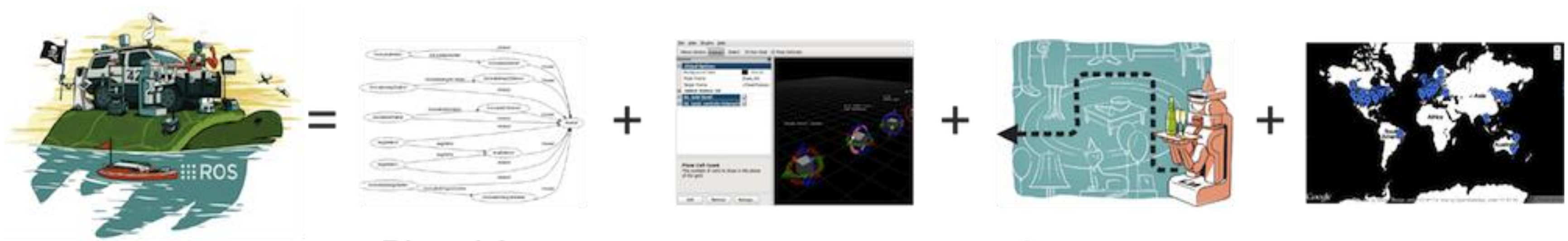




Human-Robot Interaction (HRI) is a field of study dedicated to understanding, designing, and evaluating robotic systems **for use by or with humans**. Interaction, by definition, requires **communication between robots and humans**

What is ROS?

- Flexible framework for writing robot software
- Tools, libraries and conventions
- Open-source



Plumbing Tools Capabilities Ecosystem

Why ROS?

- Creating truly robust, general-purpose robot software is **hard**
  - From the robot's perspective, problems that seem trivial to humans often vary wildly between instances of tasks and environments.
  - Dealing with these variations is so hard that no single individual, laboratory, or institution can hope to do it on their own

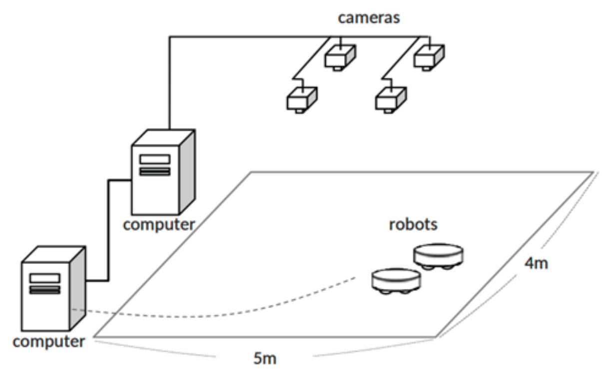
ROS Core Components

- **Executable**
  - ROS Nodes
- **Communication**
  - ROS Messages, ROS Topics
  - Publisher and Subscriber
  - ROS Services, ROS Actionlibs
- **Record and playback**
  - ROS Bags
- **Visualization**
  - rviz

ROS Nodes

- **A ROS Node is an executable process that uses ROS to communicate with other Nodes**
- **E.g., Magic Cards**
  - The cameras need to see
    - CameraDriver
  - The “magic cards” need to be understood
    - Parser
  - The robots need to be localized at all time
    - Localization
  - The parsed card info needs to be aggregated as a plan for execution
    - Planner
  - The plan needs to be break down into low-level control commands
    - RobotDriver

Magic Cards



hardware

ROS Node

N Cameras

CameraDriver

Computer/Server

Parser

Planner

Localization

M Robots

RobotDriver

ROS Messages

- A **ROS Message** is a ROS data type for communication among the Nodes
- ROS built-in default message types
  - **std_msgs**
    - basic data types, such as int, float, string
  - **geometry_msgs**
    - geometry-related data types, such as point, vector, pose
  - **sensor_msgs**:
    - sensory data types, such as batterystate, image, pointcloud
  - etc…
- Customized message type
  - Developer can define a new message type using the existing message types

std_msgs

- **Basic**
  - Bool, Byte, Char
  - Int8, Int16, Int32, Int64,
  - UInt8, UInt16, UInt32, UInt64
  - Float32, Float64
  - String
  - Time, Duration
- **Signal**
  - Empty: a message usually used as a signal
- **Compound**
  - Header: a message in sequence with timestamp
  - ColorRGBA: a message to describe a pixel

std_msgs/Header.msg

```
uint32      seq
time        stamp
string      frame_id
```

std_msgs/ColorRGBA.msg

```
float32     r
float32     g
float32     b
float32     a
```

std_msgs (cont)

- **Array-related**
  - MultiArrayDimension

```
std_msgs/MultiArrayDimension.msg

string  label
uint32  size
uint32  stride
```

  - IntXXMultiArray, UIntXXMultiArray, FloatXXMultiArray

```
std_msgs/Int16MultiArray.msg

MultiArrayLayout      layout
uint8[]               data
```

std_msgs (cont)

- **Array-related**
  - MultiArrayLayout

```
std_msgs/MultiArrayLayout.msg

MultiArrayDimension[]   dim
uint32                  data_offset
```

E.g., a standard, 3-channel 640x480 image with interleaved color channels:

```
dim[0].label = "height"
dim[0].size = 480
dim[0].stride = 3*640*480
dim[1].label = "width"
dim[1].size = 640
dim[1].stride = 3*640
dim[2].label = "channel"
dim[2].size = 3
dim[2].stride = 3
```

geometry_msgs

- **Pose related**
  - Point, Point32, PointStamped
  - Quaternion, QuaternionStamped
  - Pose, Pose2D, PoseStamped, PoseWithCovariance, PoseWithCovarianceStamped
  - PoseArray
- **Control related**
  - Vector3, Vector3Stamped
  - Transform, TransformStamped
  - Twist, TwistStamped, TwistWithCovariance, TwistWithCovarianceStamped
  - Wrench, WrenchStamped
- **Etc.**

geometry_msgs (cont)

geometry_msgs/Pose.msg

```
Point           position
Quaternion      orientation
```

geometry_msgs/PoseStamped.msg

```
Header          header
Pose            pose
```

geometry_msgs/Point.msg

```
float64         x
float64         y
float64         z
```

geometry_msgs/Quaternion.msg

```
float64         x
float64         y
float64         z
float64         w
```

sensor_msgs

- **Camera related**
  - RegionOfInterest, CameraInfo
  - Image, CompressedImage
- **PointCloud related**
  - LaserEcho, LaserScan, MultiEchoLaserScan
  - PointCloud, PointCloud2
- **GPS related**
  - NavSatFix, NavSatStatus
- **Joystick related**
  - Joy, JoyFeedback, JoyFeedbackArray
- **Others**
  - BatteryState, Temperature, RelativeHumidity, FluidPressure, etc

Customized Message

- Create a msg file
- Follow the format of the default message
- Add in the fields using already defined message types
- E.g.

std_msgs/Header.msg

```
uint32          seq
time            stamp
string          frame_id
```

msgs/MagicCard.msg

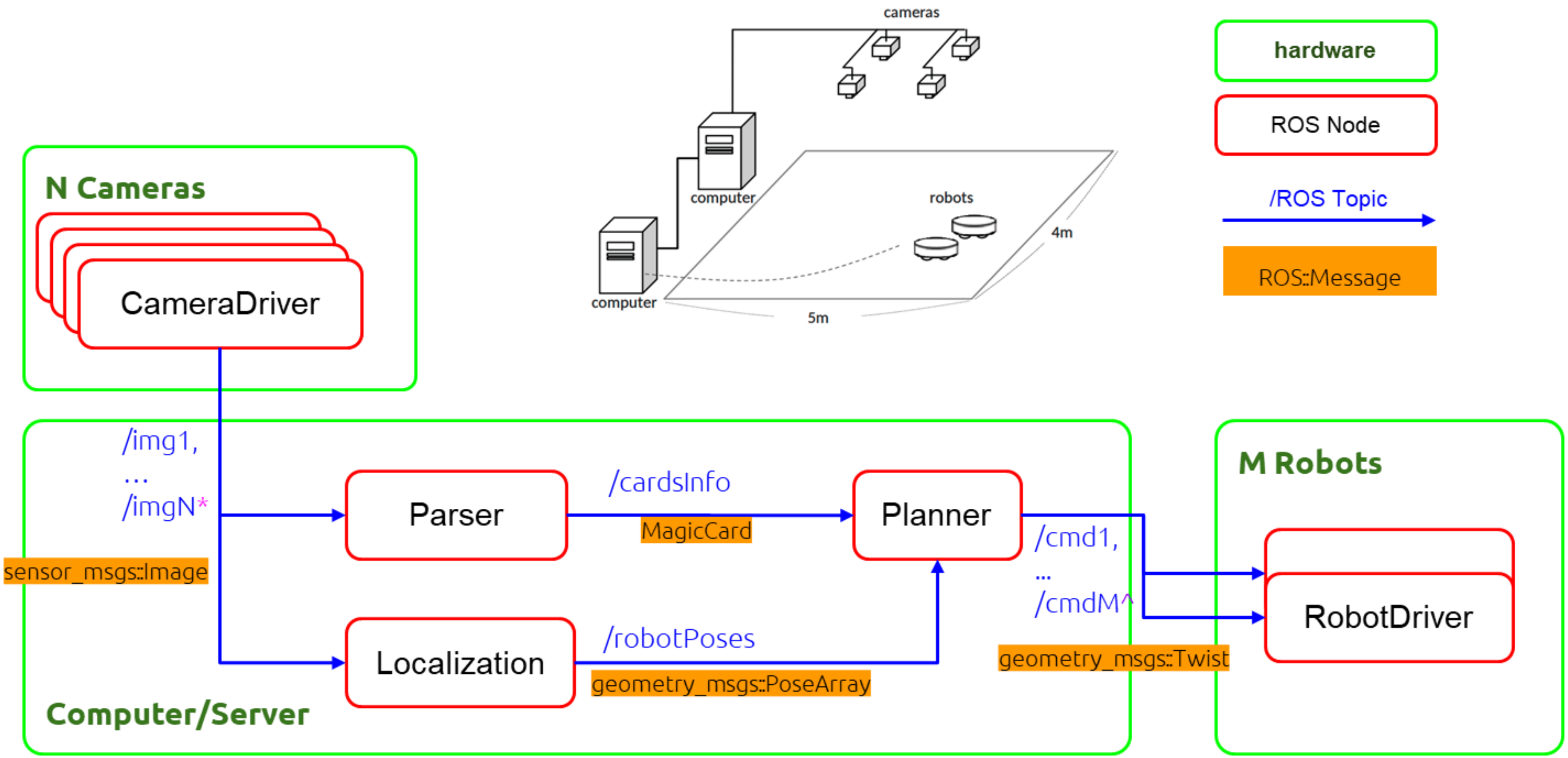
```
uint32          card_id
string          card_txt
time            stamp
pose2D          pose
twist           control
...
```

ROS Topics **(RECAP)**

- 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

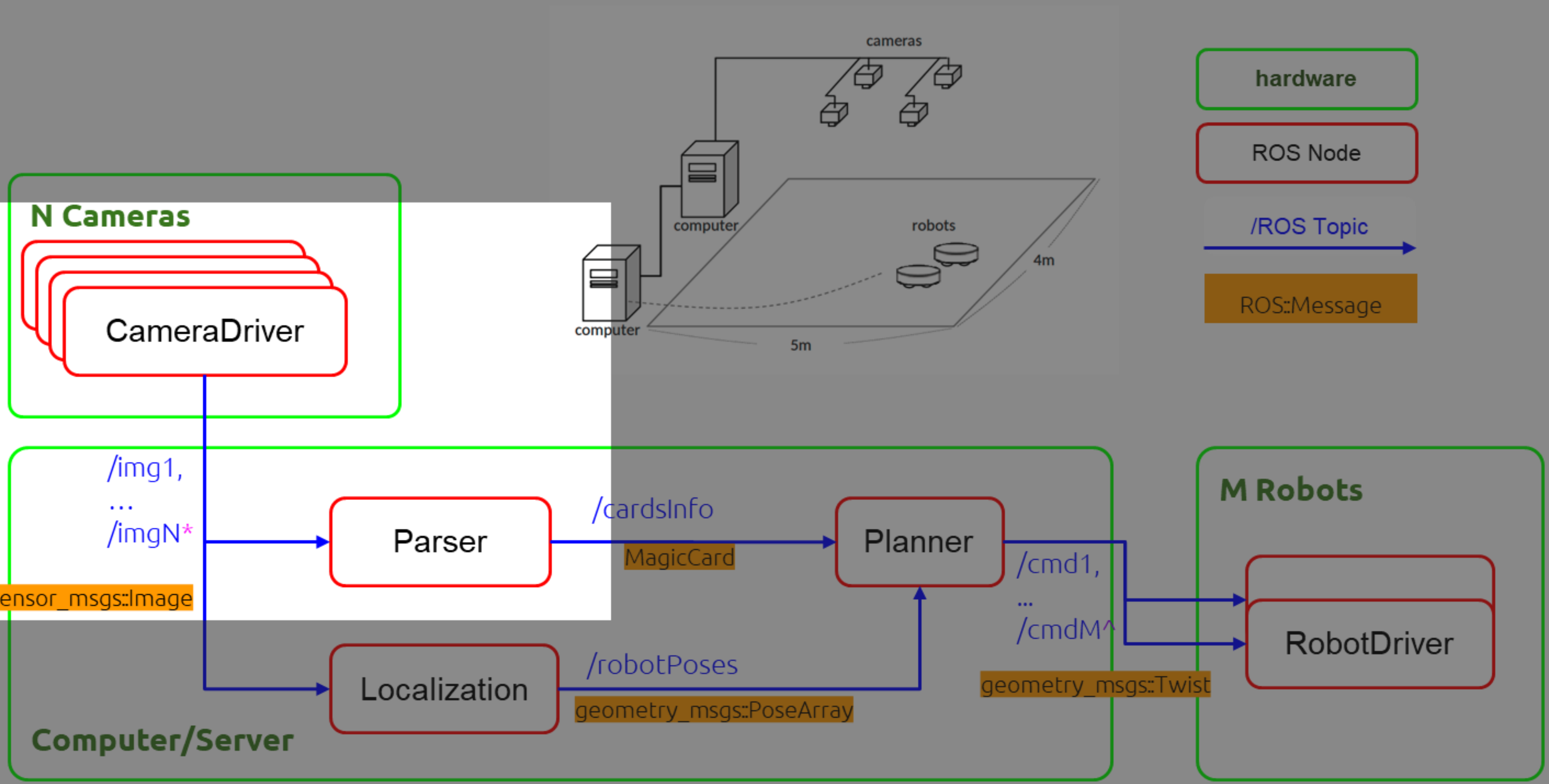
Magic Cards (v1.0)



*The Parser subscribes all N topics published by the N CameraDrivers.

^The Planner publishes M topics subscribed by the M RobotDrivers respectively.

Magic Cards (v1.0)



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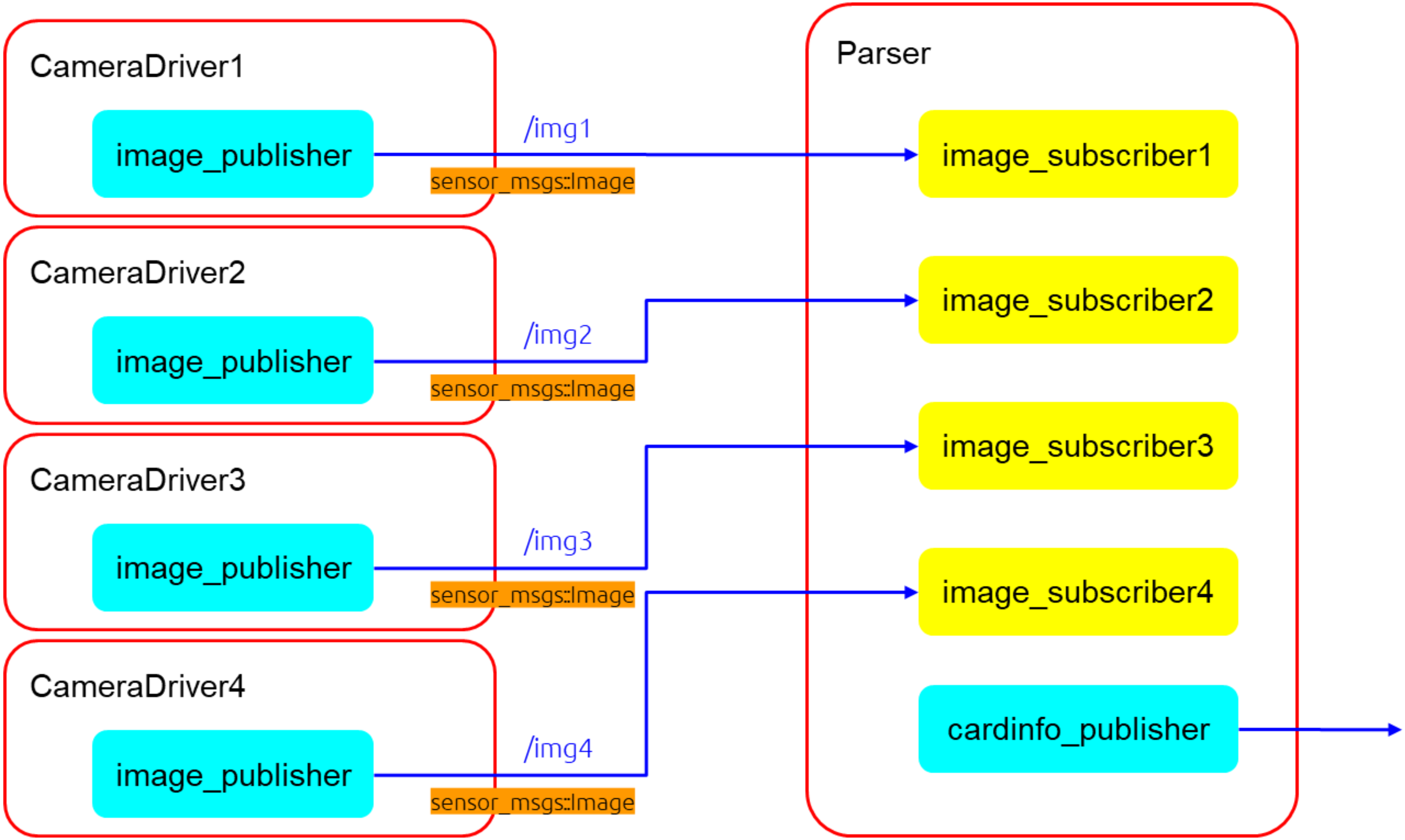
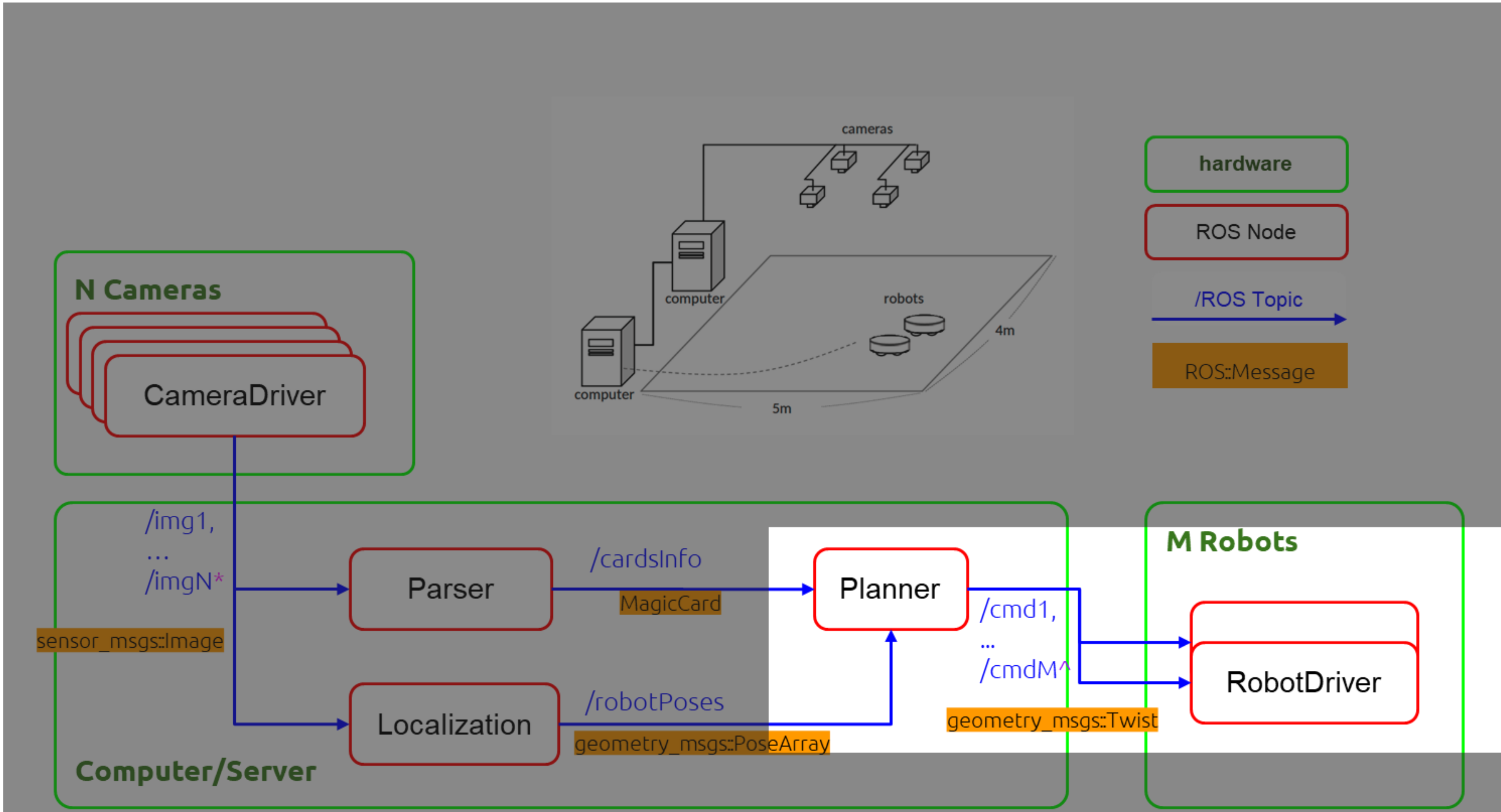
Publisher and Subscriber (v1.0)



Magic Cards (v1.0)



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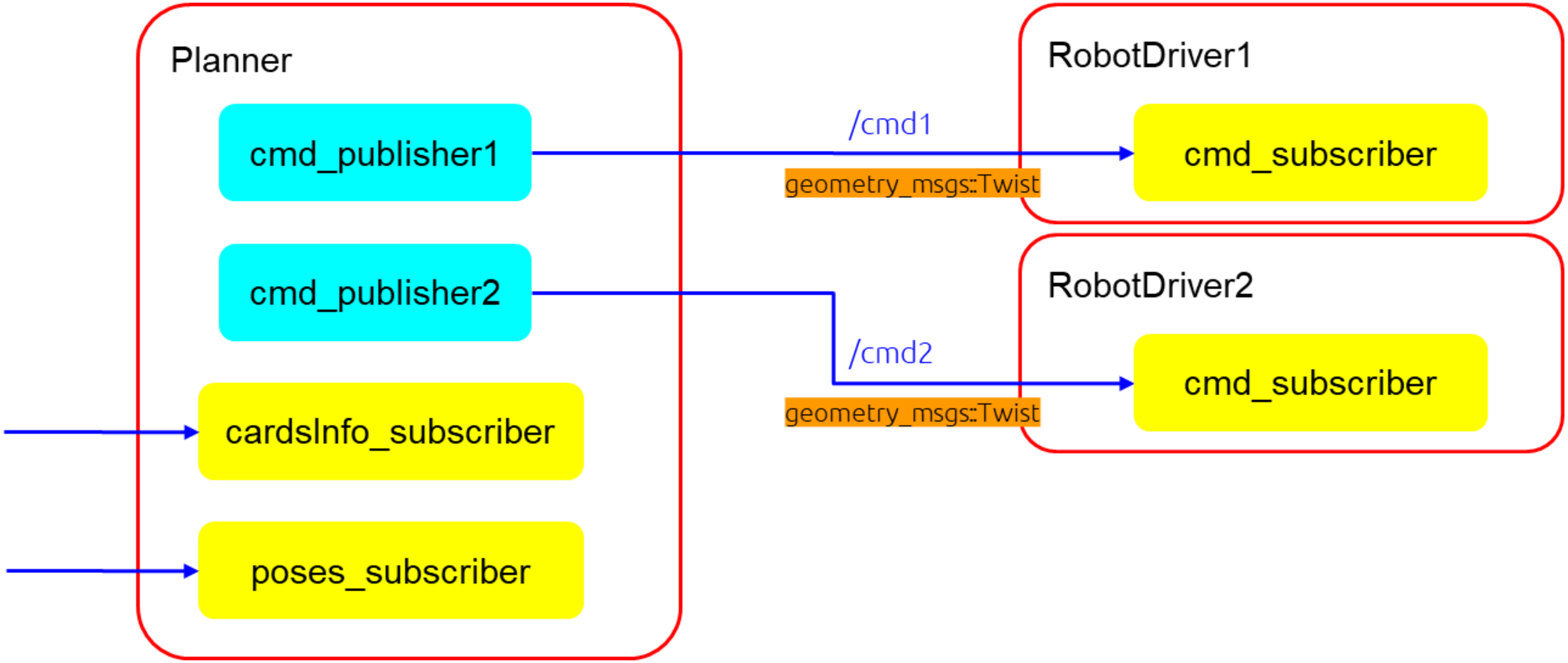
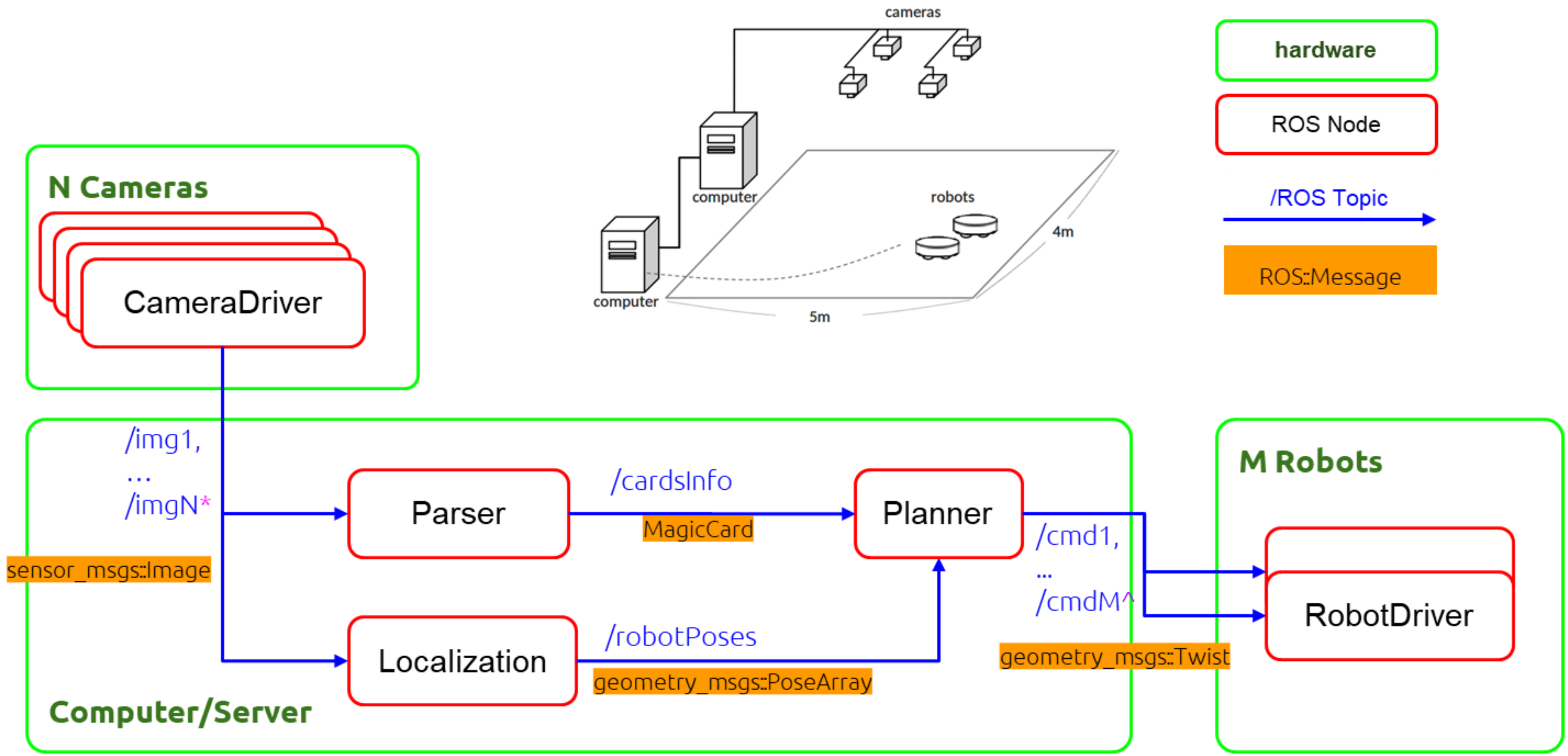
Publisher and Subscriber (v1.0) cont



Magic Cards (v1.0)



*The Parser subscribes all N topics published by the N CameraDrivers.

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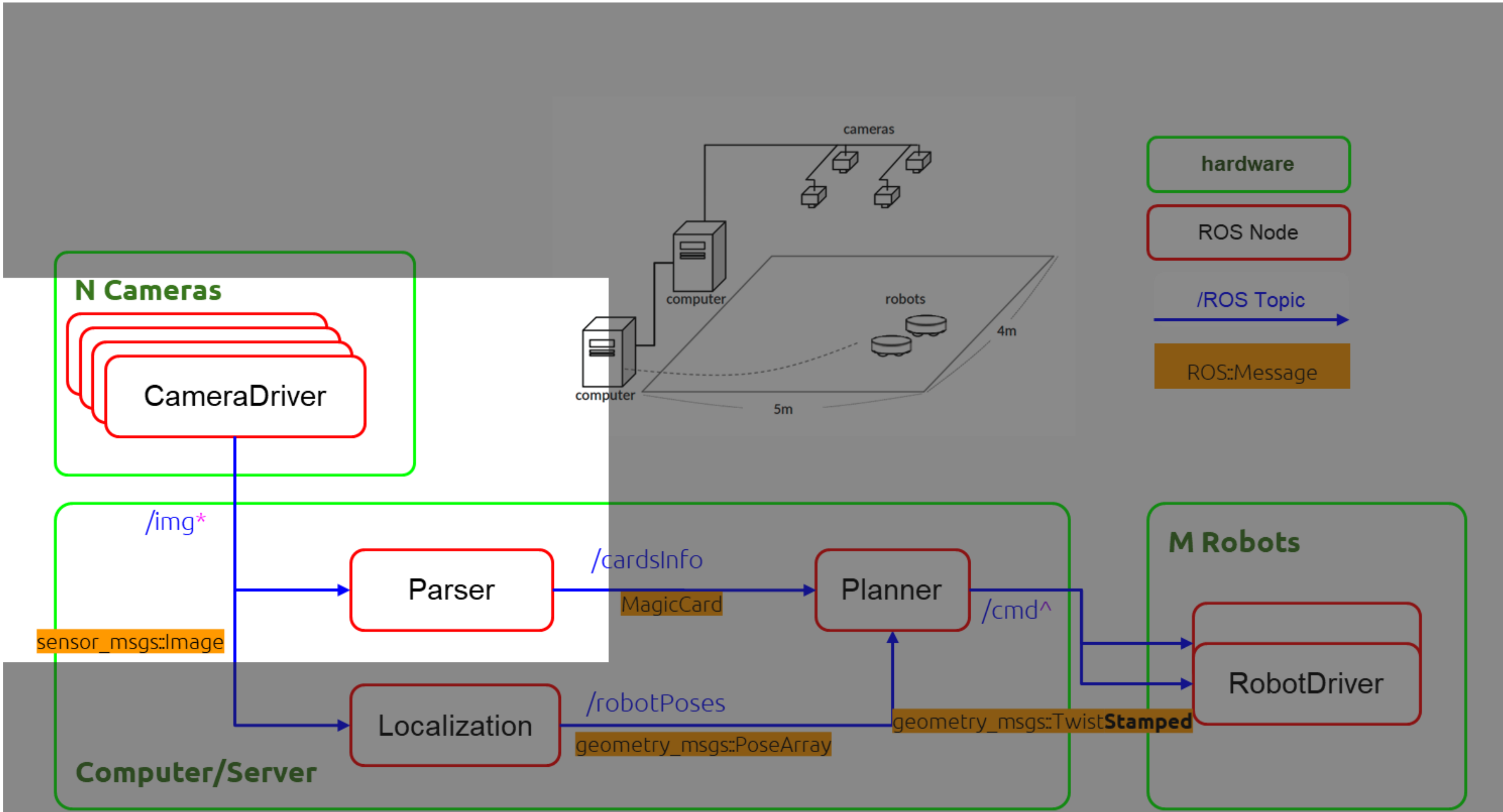
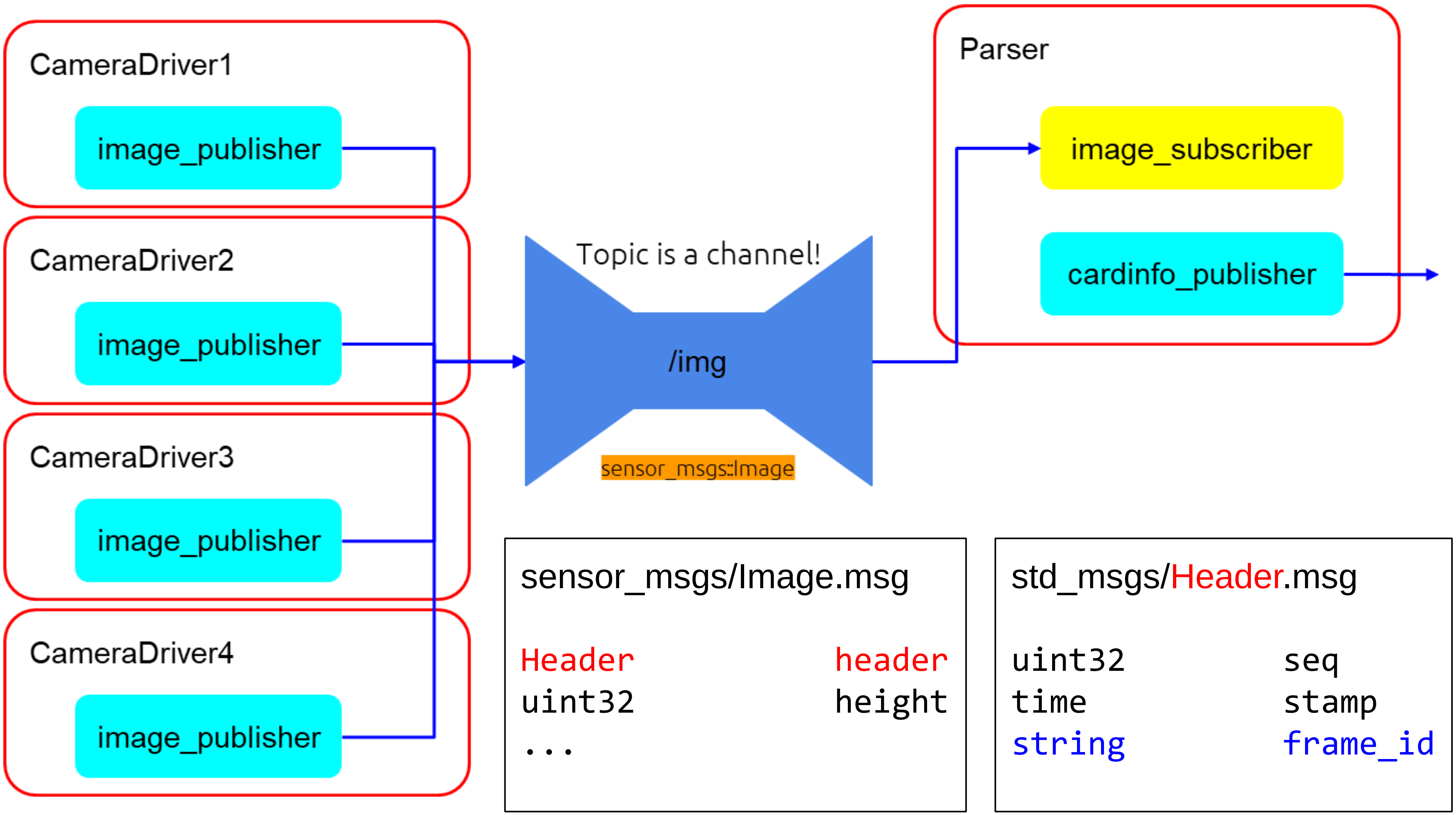
Magic Cards (v2.0)



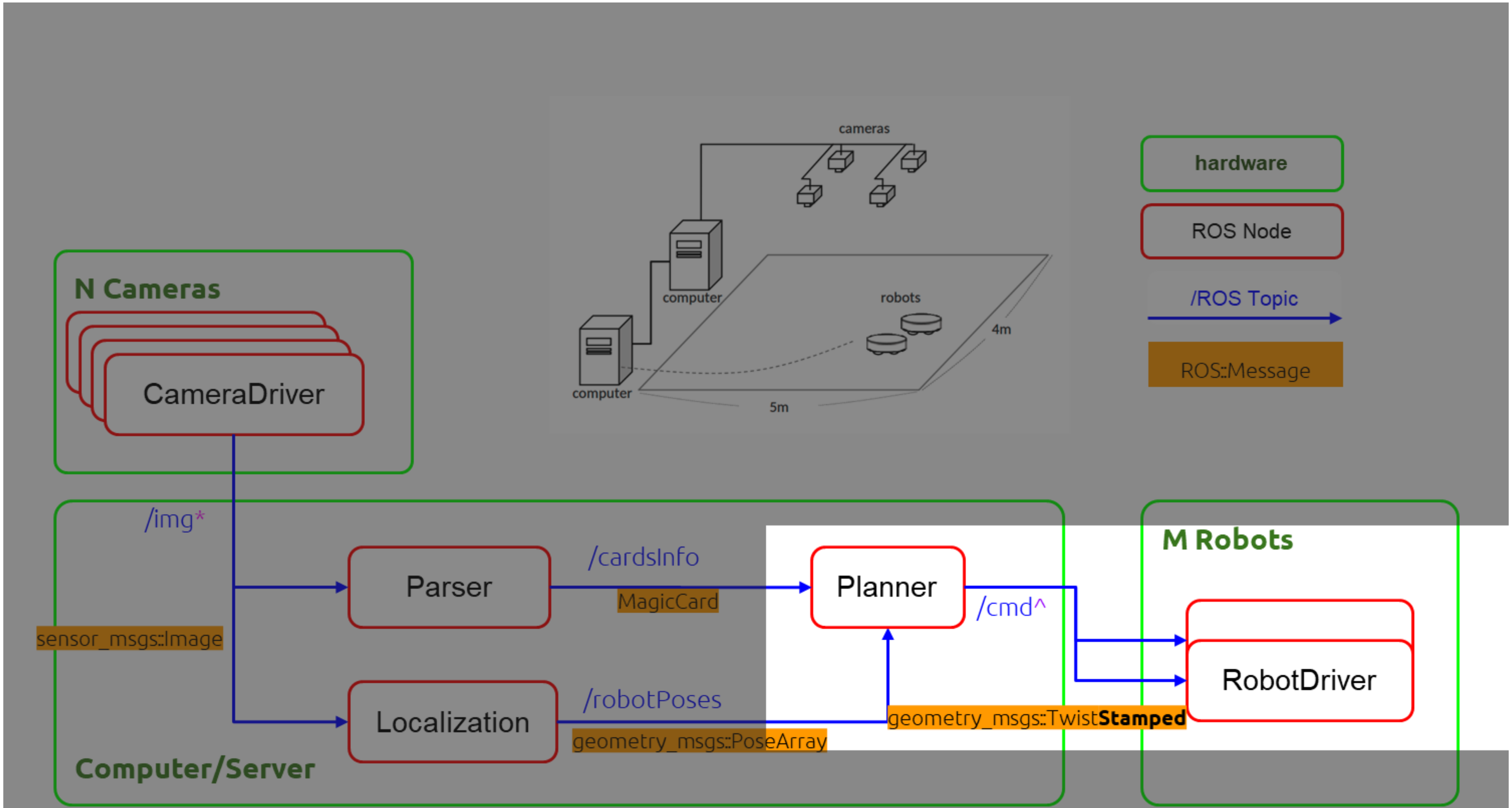
*All N CameraDrivers publish on 1 topic with different Header::frame_ids.

^Similarly, the Planner publishes on 1 topic subscribed by all M RobotDrivers.

Publisher and Subscriber (v2.0)



Magic Cards (v2.0)



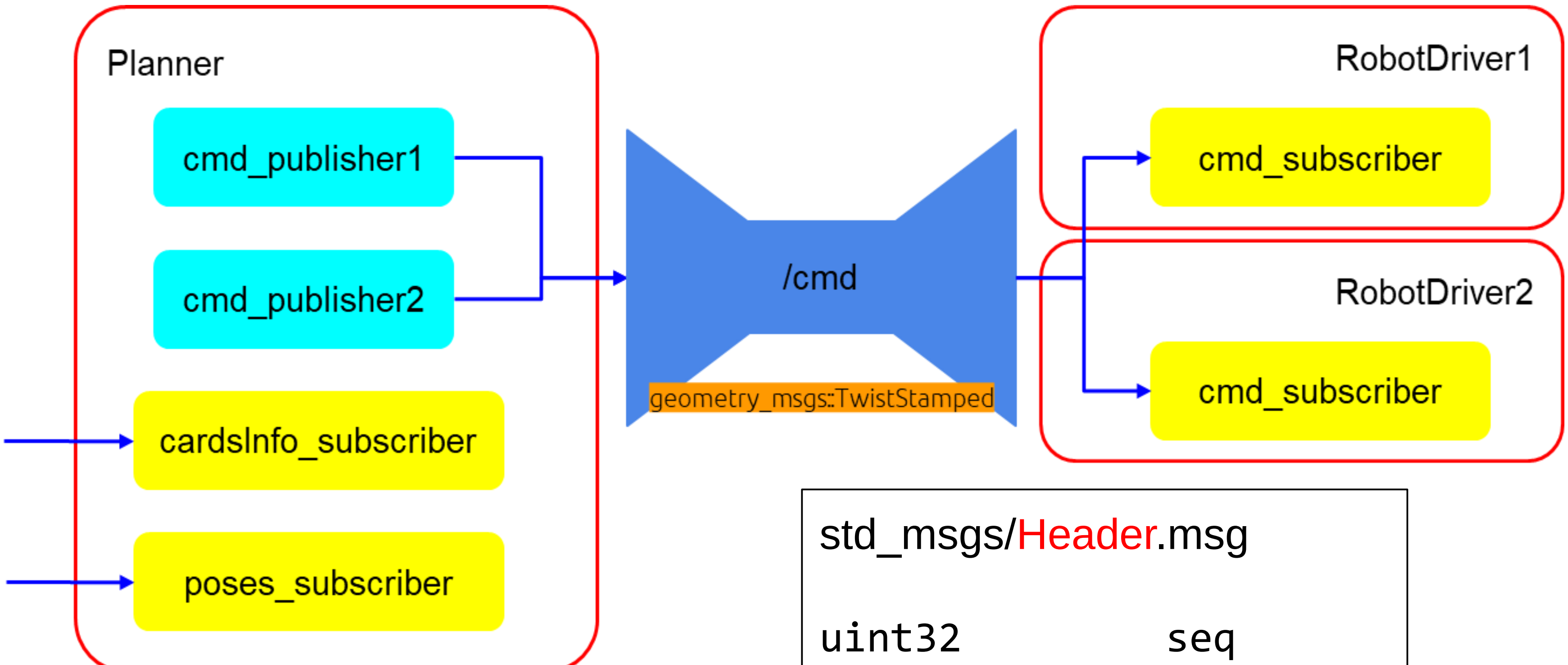
*All N CameraDrivers publish on 1 topic with different Header::frame_ids.

^Similarly, the Planner publishes on 1 topic subscribed by all M RobotDrivers.

Publisher and Subscriber (v2.0)

geometry_msgs/TwistStamped.msg

```
Header          header
Twist           twist
```



std_msgs/Header.msg

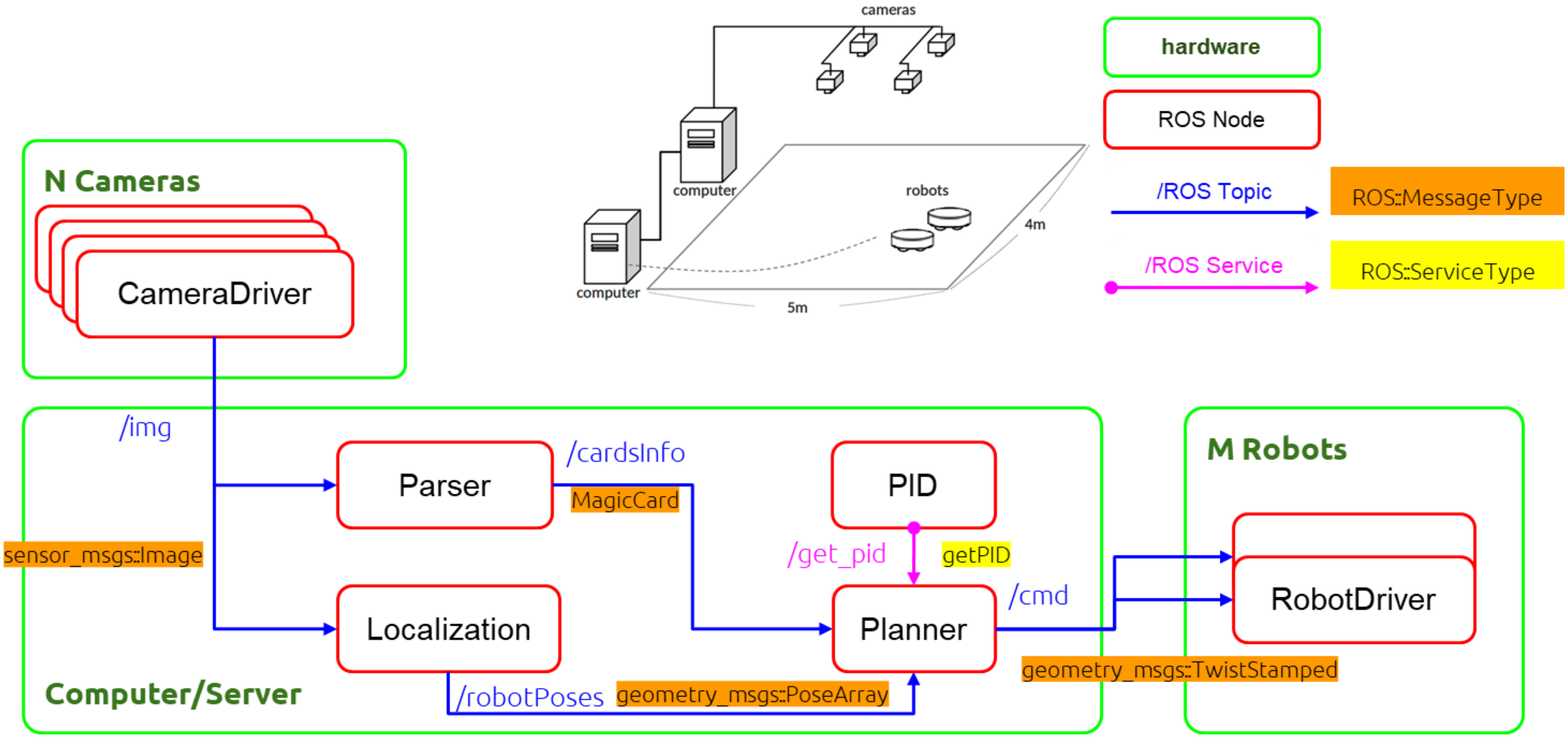
```
uint32          seq
time            stamp
string          frame_id
```

ROS Services

The **publish / subscribe** model is a very flexible communication paradigm, but its many-to-many one-way transport is not appropriate for **request / reply** interactions

- **ROS Services** are another way that nodes can communicate with each other (i.e. two-way)
- ROS Services allow nodes to send a request and receive a response
- **ROS built-in services**
- **Customized service**
  - Developer can define a new service call based on existing message types

Magic Cards (v3.0)



Built-in Service in sensor_msgs

sensor_msgs/setCameraInfo.srv

```
CameraInfo          info
---
bool                success
string              status_message
```

Request

Response

Customized Service

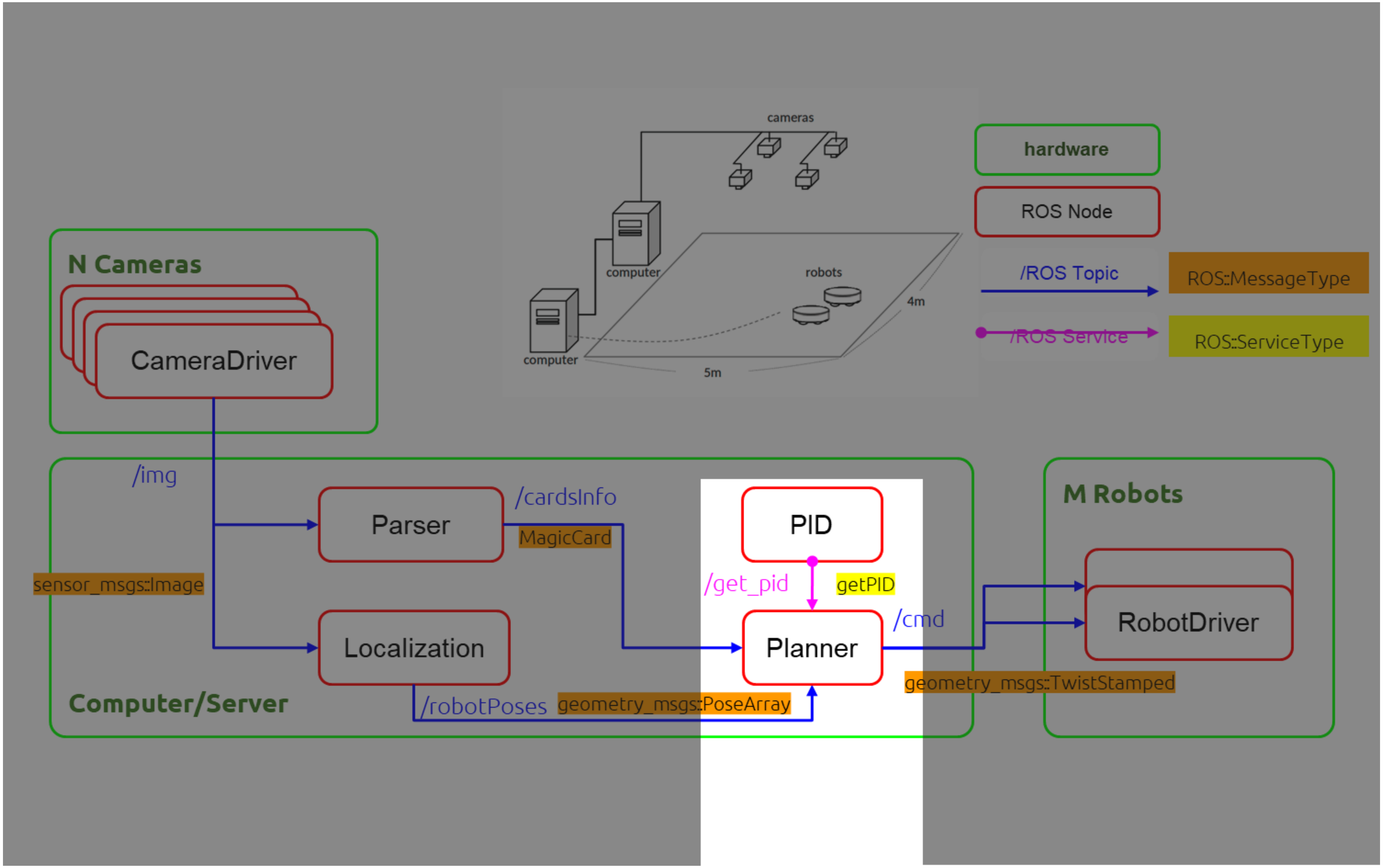
sensor_msgs/setCameraInfo.srv

```
CameraInfo     info
---
bool           success
string         status_message
```

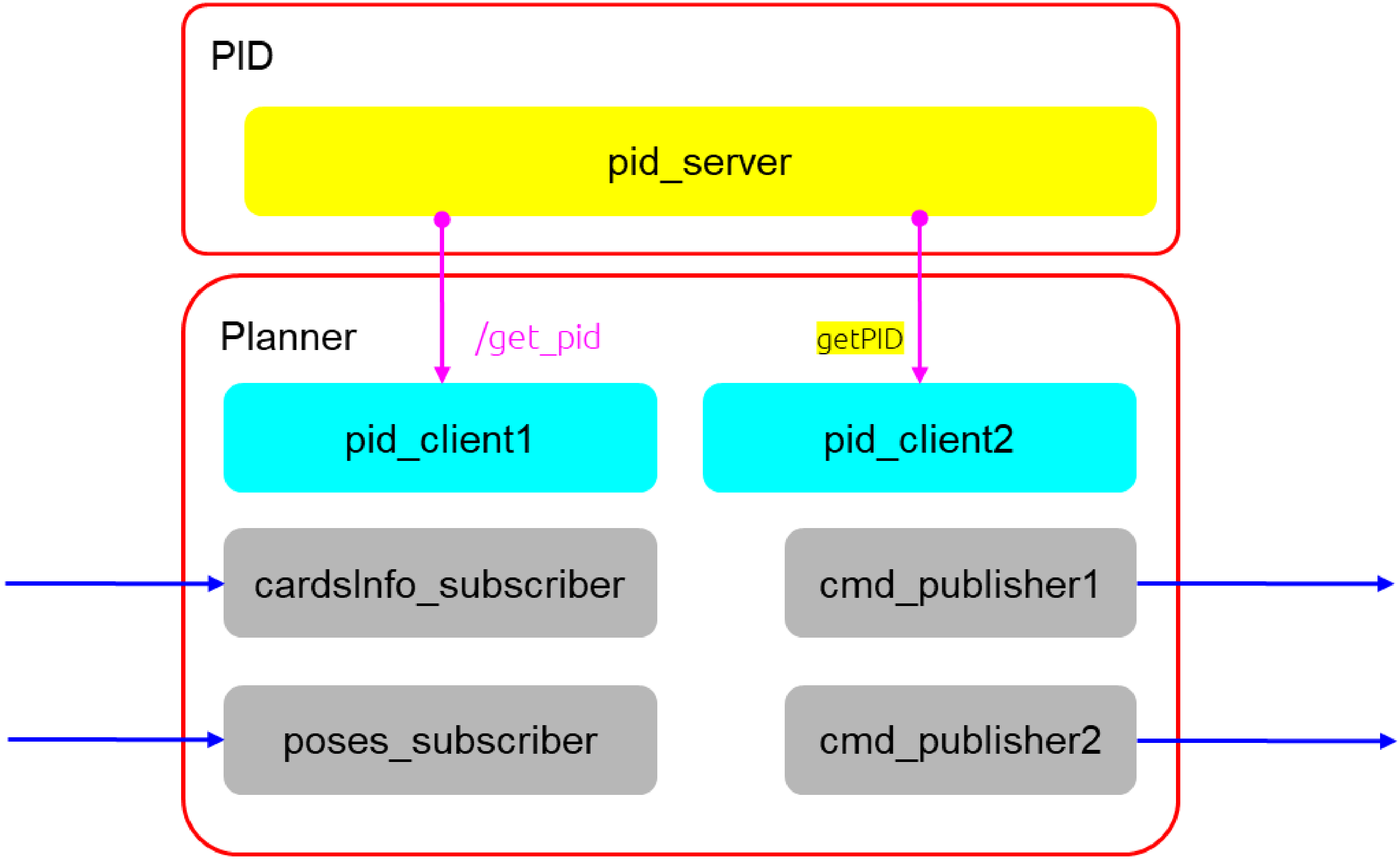
srvs/getPID.srv

```
Pose           goal_pose
Pose           current_pose
---
Twist          twist
```

Magic Cards (v3.0)



Service and Client



ROS Architecture Construction (Practice)

Consider an autonomous drone that is in an environment with humans. You are required to **consider the following components and the respective features:**

1. One camera for it to see; its collected data aid in the localization of the robot and the machine vision system
2. A computer to identify things (be it humans or objects), to plan routes, and to localize the robot
3. The motors for the propellers

ROS Architecture Construction (Practice)

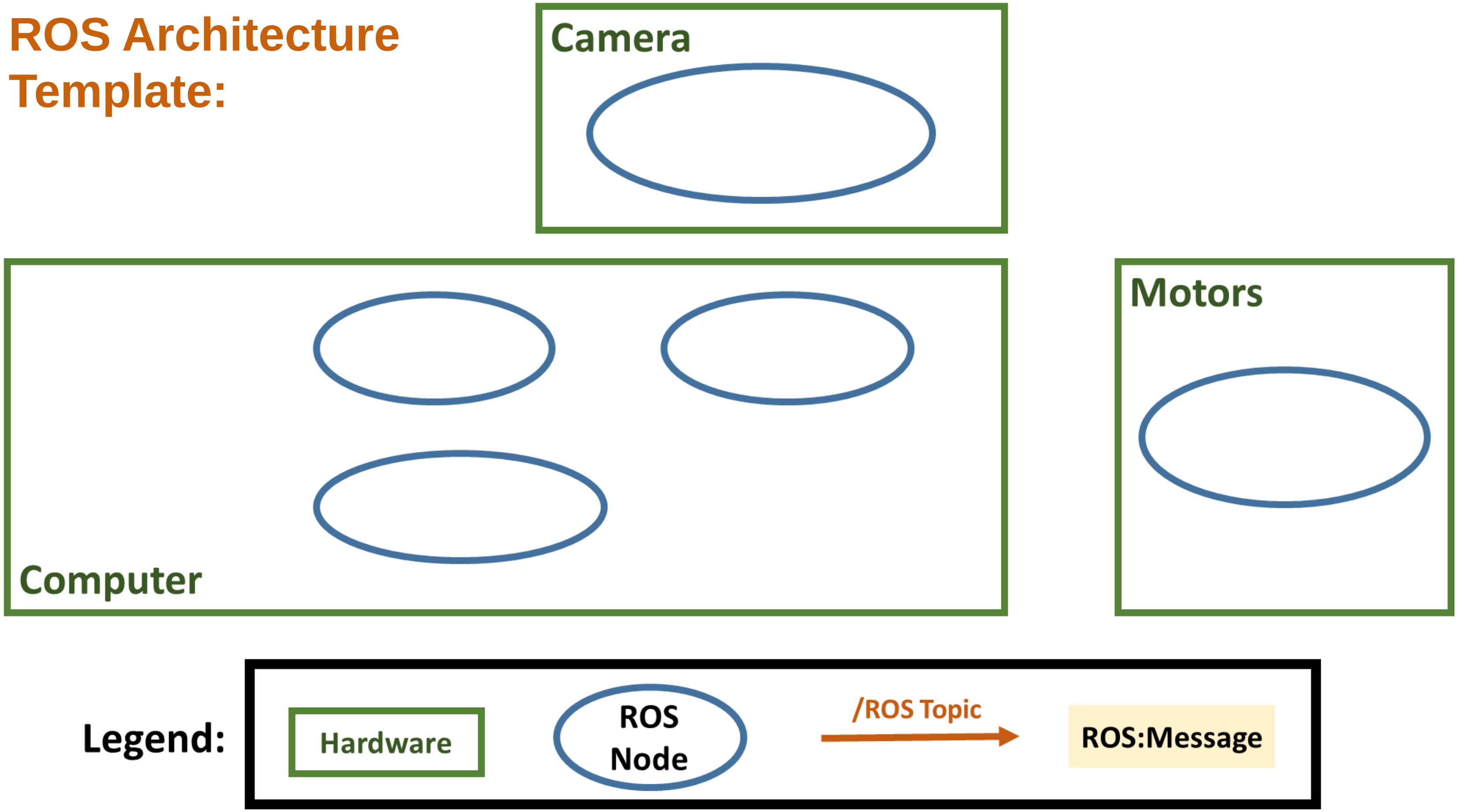
Based on the below information, **construct a ROS architecture** using the given template, “ROS Architecture Template”.

The various **node names** that are required for the ROS programme for this drone, together with their respective **topics and messages** involved are summarized in the table below (assume only topics are used):

Hardware	ROS Node	/ROS Topic	ROS:Message
Camera	CameraDriver	/image	sensor_msgs::Image
Computer	MachineVision	/thingsData	Things
	Localization	/pose	geometry_msgs::PoseArray
	Planner	/cmd	geometry_msgs::Twist
Motors	MotorDriver	N.A.	N.A.

ROS Architecture Construction (Practice)

ROS Architecture Template:



Extra: ROS Actionlibs

In some cases, if the service takes a long time to execute, the developer might want the ability to cancel the request during execution or get periodic feedback about how the request is progressing.

- **ROS Actionlibs** create servers that execute long-running goals that can be preempted
- ROS Actionlibs provide a client interface to send requests to the server

action/CleanRooms.action

```
uint32[]        room_ids
---
uint32          total_rooms_cleaned
---
float32         percentage_completed
```

Goal

Result

Feedback

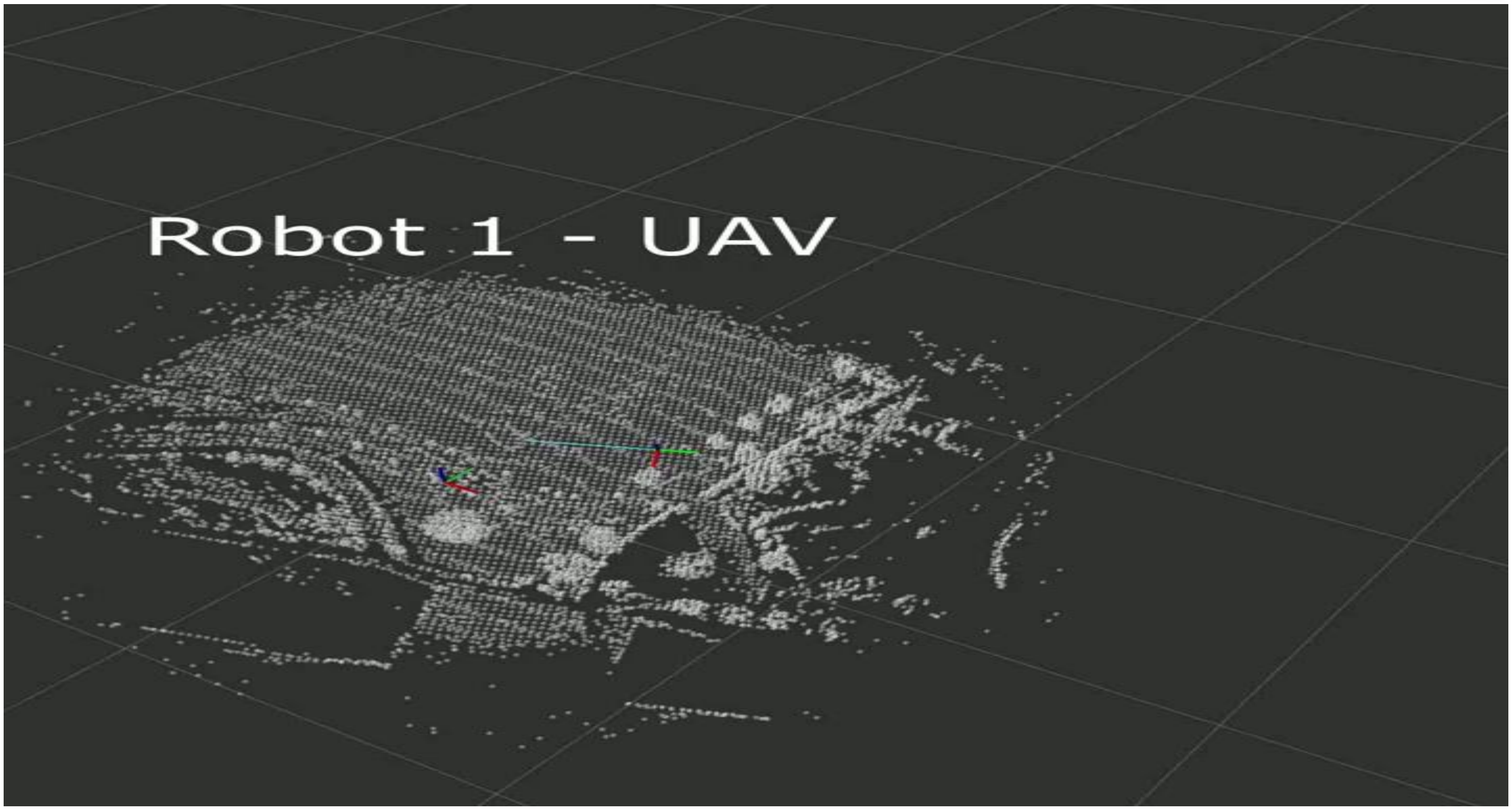
ROS Bags

Real-world robot data are generally hard and costly to acquire. **ROS Bags** enables easy record / playback for store, process, analysis and visualization, etc.

- **Record**
  - A ROS Bag is a special Node that subscribes to one or more Topics, and stores the message data in a file as it is received.
- **Playback**
  - The bag files can also be played back in ROS to the same topics they were recorded from.

Data Playback on Collaborative 3D SLAM

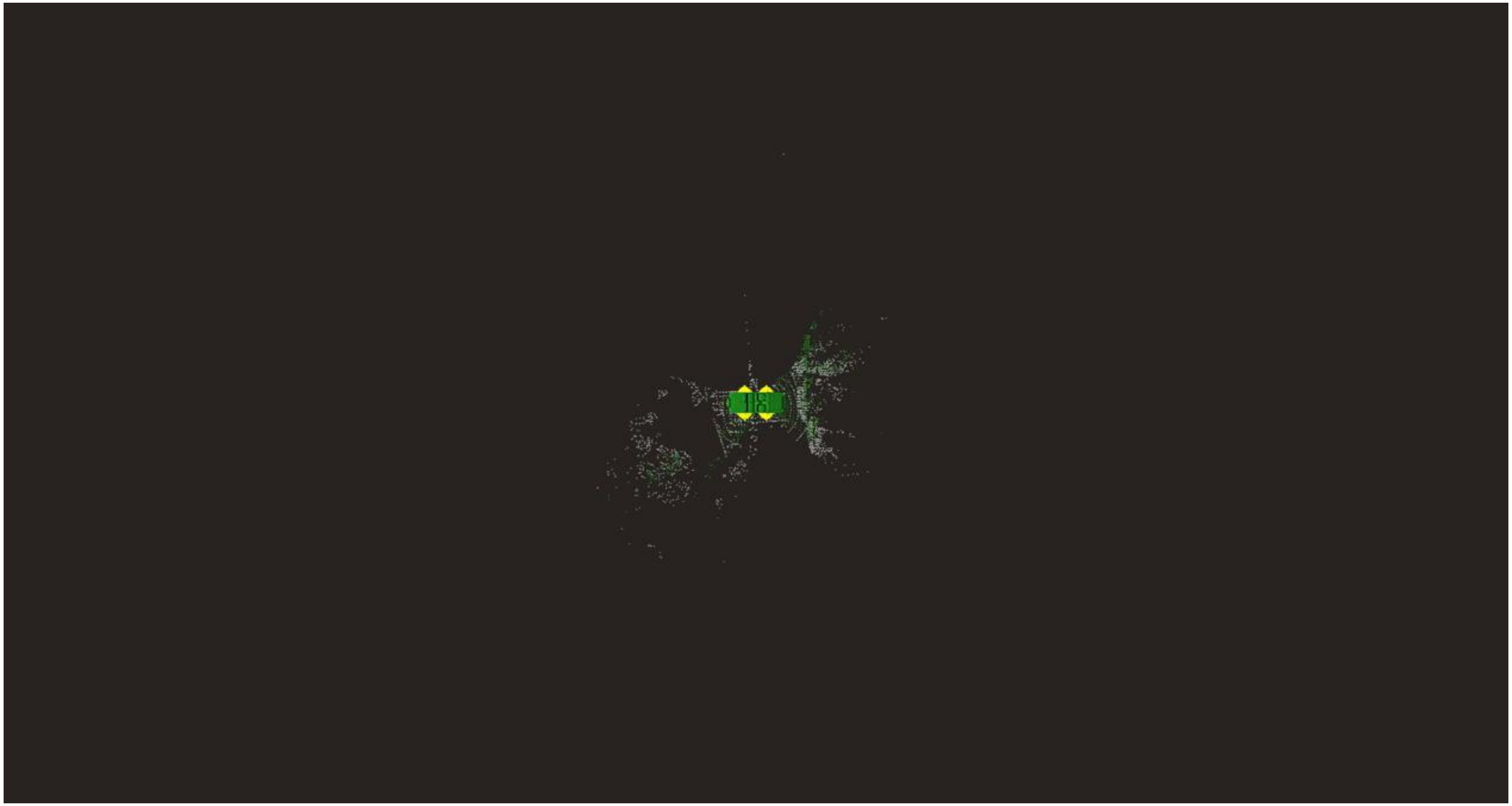
Collaborative SLAM between UAV and UGV



Source: https://www.youtube.com/watch?v=ZZQT_REkItU

Data Playback on Collaborative 3D SLAM (cont)

Collaborative SLAM in NUS forest



Source: https://www.youtube.com/watch?v=1JoPp7GbN4E

Extra: practical issues

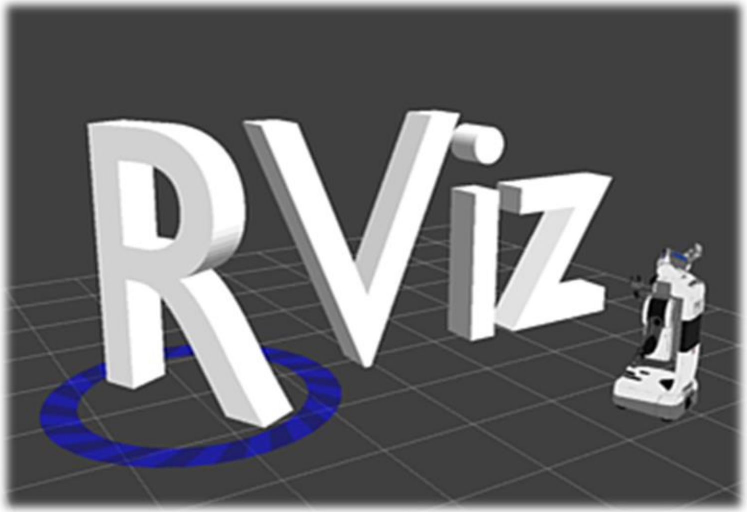
ROS is a middleware which faces practical problems while passing data around

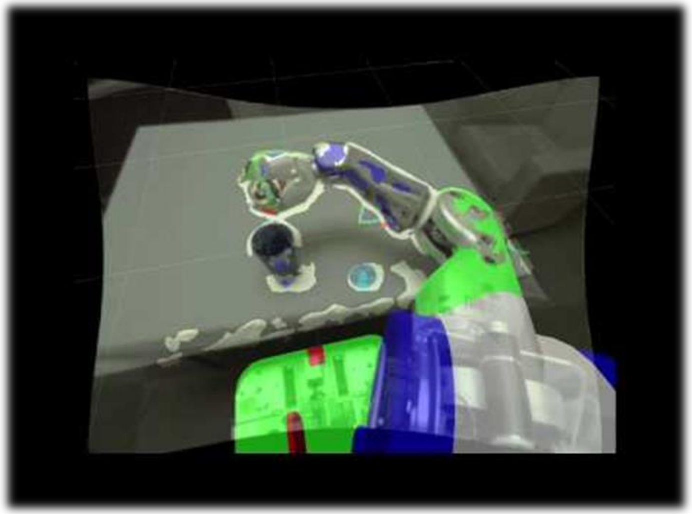
- **Data loss**
  - Network breaks down
- **Data delay**
  - Data may not be received in order
- **Data non-synchronization**
  - Messages played back from the Bags at the recorded pace

ROS Visualization

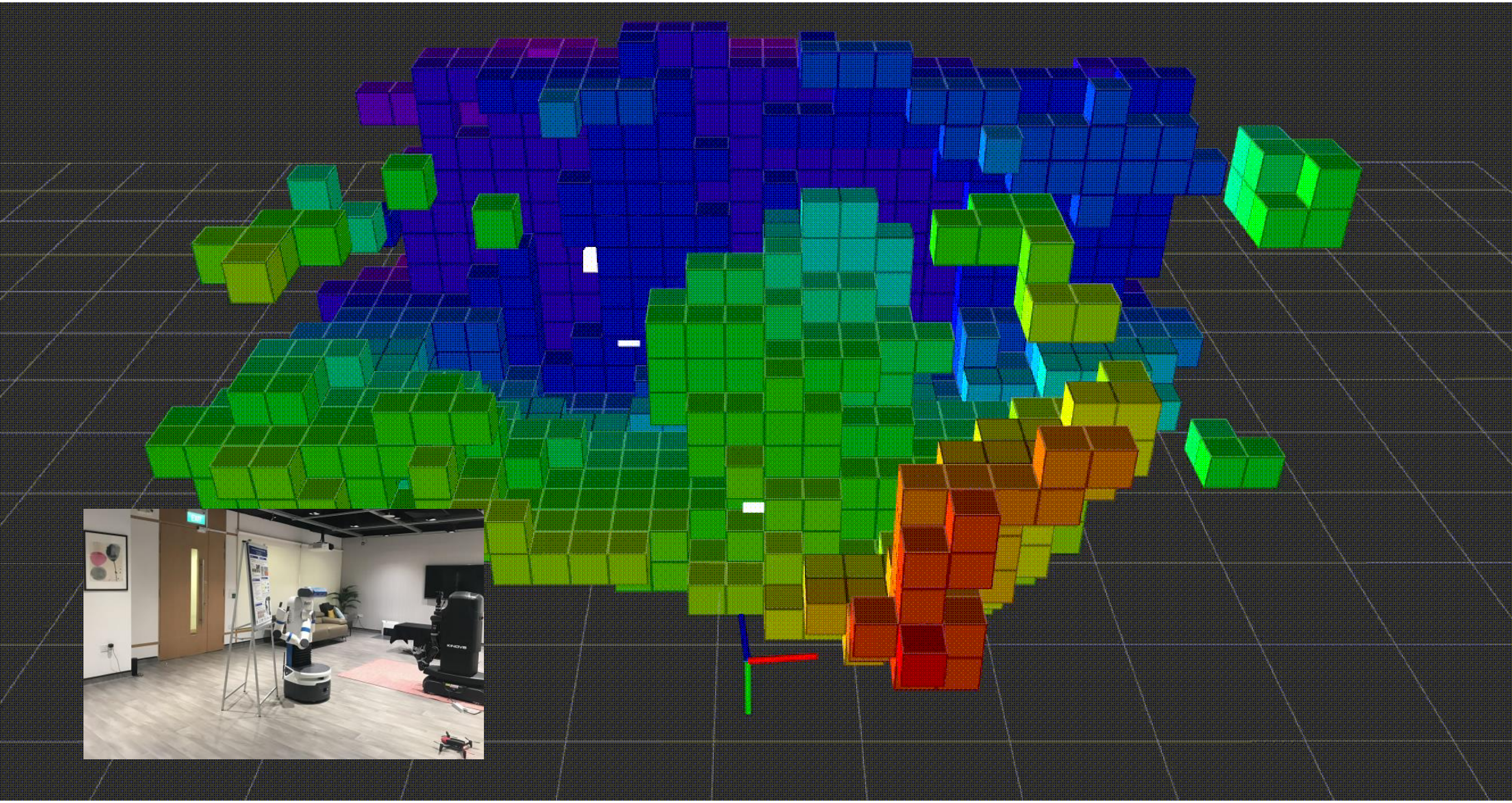
RViz is the goto (built-in) 3D visualizer for ROS

It is essentially a Node subscribing a fixed set of Message types to be visualized

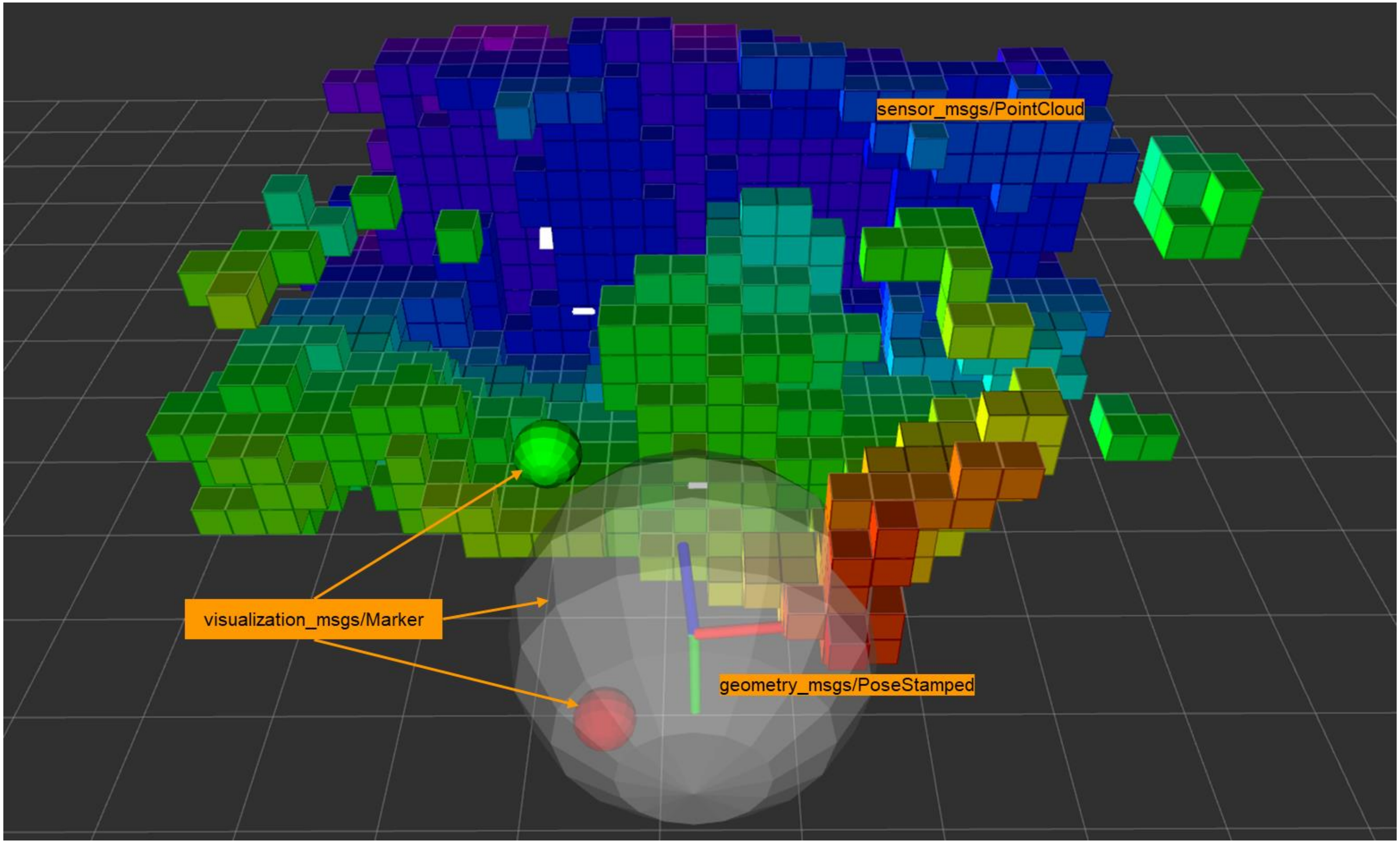




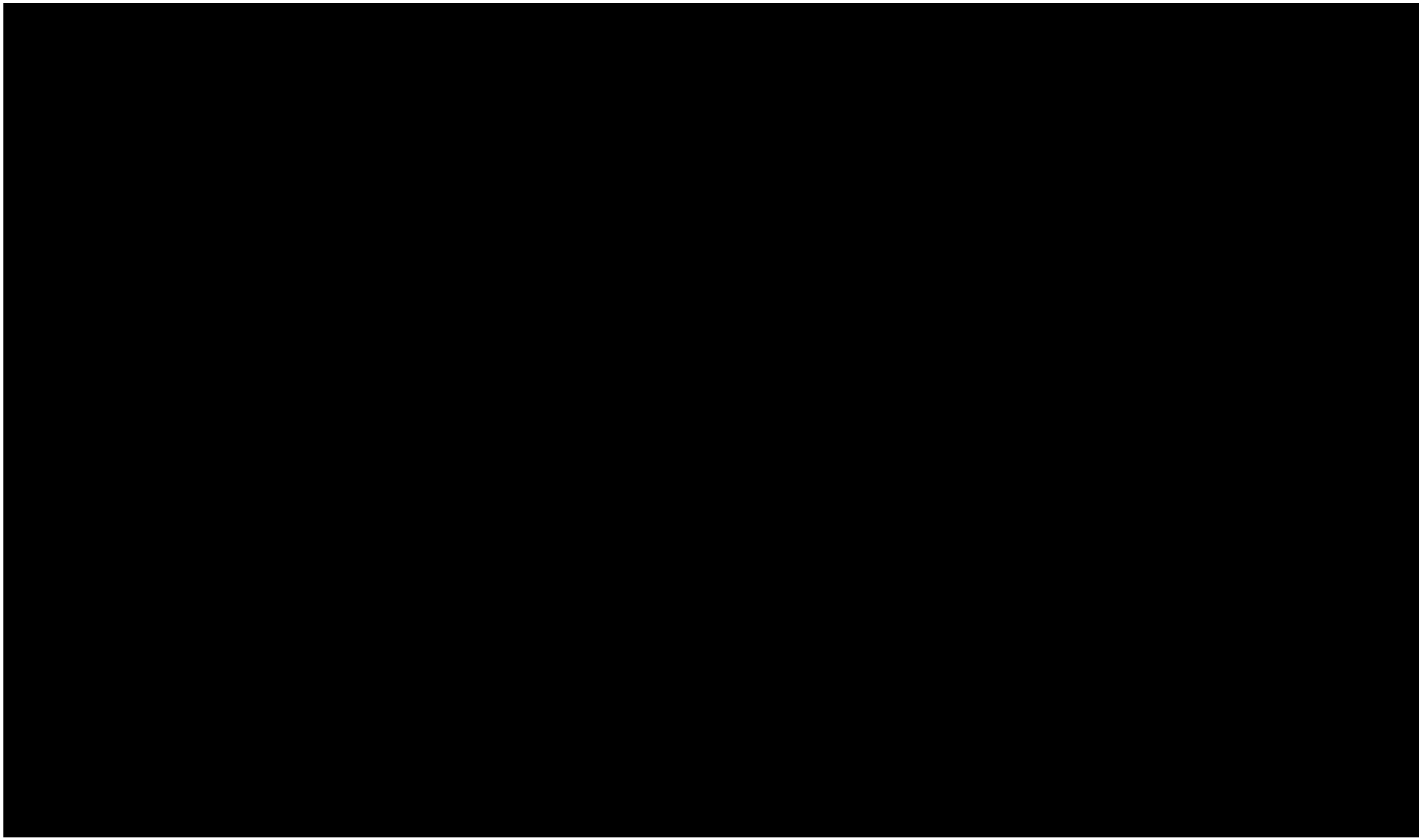
ROS Visualization (Example: Collision Avoidance)



ROS Visualization (Example: Collision Avoidance)



ROS Visualization (Example: Collision Avoidance)

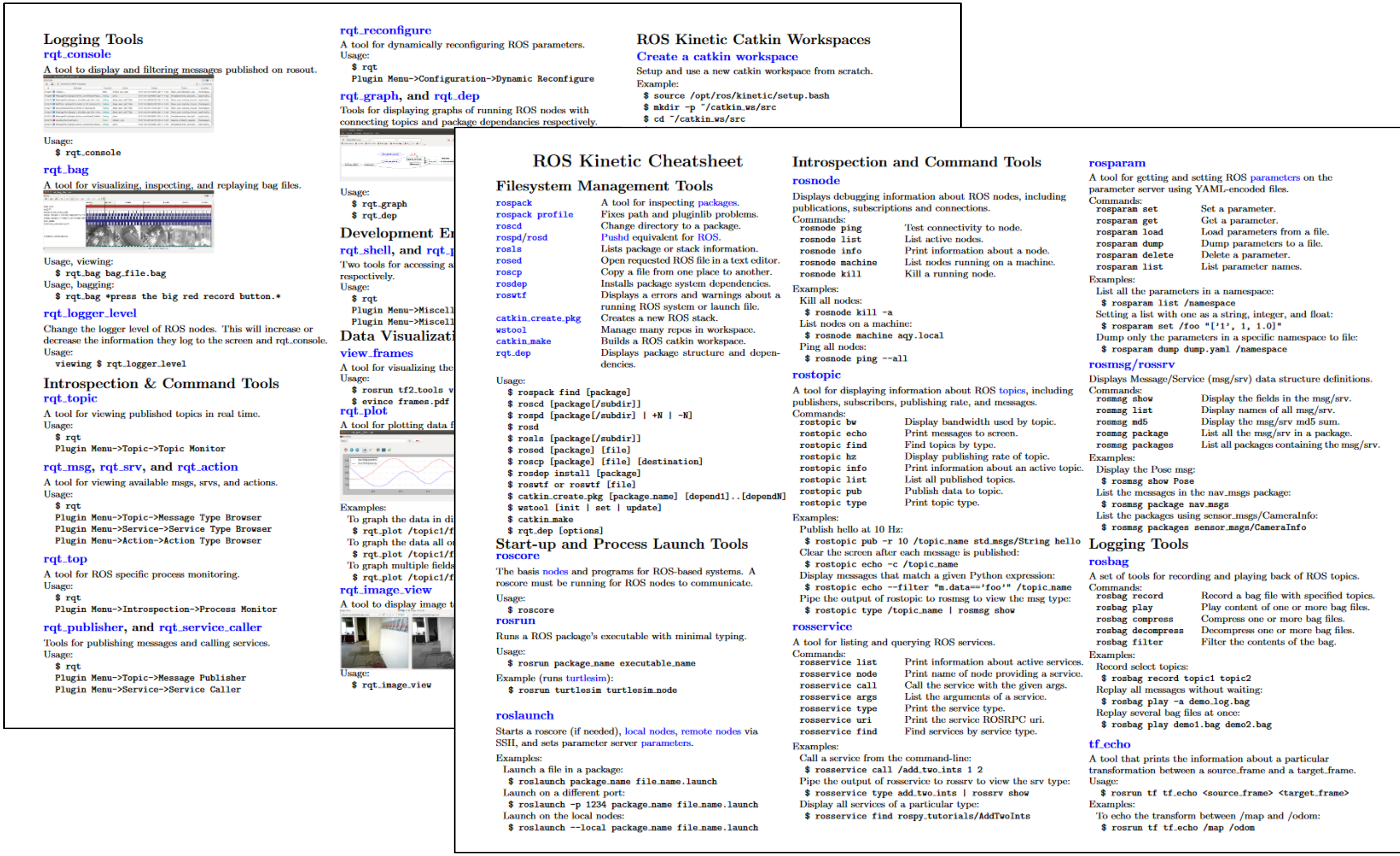


Source: https://www.youtube.com/watch?v=pUOdwGLYmN8

ROS cheatsheet

ISO 29100:2010

NUS National University of Singapore



https://w3.cs.jmu.edu/spragunr/CS354_S19/handouts/ROSCheatsheet.pdf

MODULE 2 WORKSHOP: WORKSHOP DAY 1

HANDS-ON ANALYSIS OF STATE-OF-THE-ART HRI PROJECTS: INTERACTIONS WITH DOMESTIC ROBOTS

Introducing Internet-of-Things (IoT)

What is IoT?

- Internet connects all people, so it is called “the Internet of People”
- **IoT connects all things**, so it is called “the Internet of Things”
- Remember the key elements of IoT:
    1. **Connect** devices
    2. **Process** (i.e. data collection, analysis and management)
    3. **Act**

Internet-of-Things (IoT) plays which important role(s) in Human-Robot Interactions (HRI)? (you may choose more than one)

Storing Data in the Cloud (i.e. online servers)

Data Analysis

Offsite Monitoring of Robotic System

Offsite Control of Robotic System (include actuators)

Offsite Alert Prompt to Humans

Start the presentation to see live content. For screen share software, share the entire screen. Get help at **pollev.com/app**

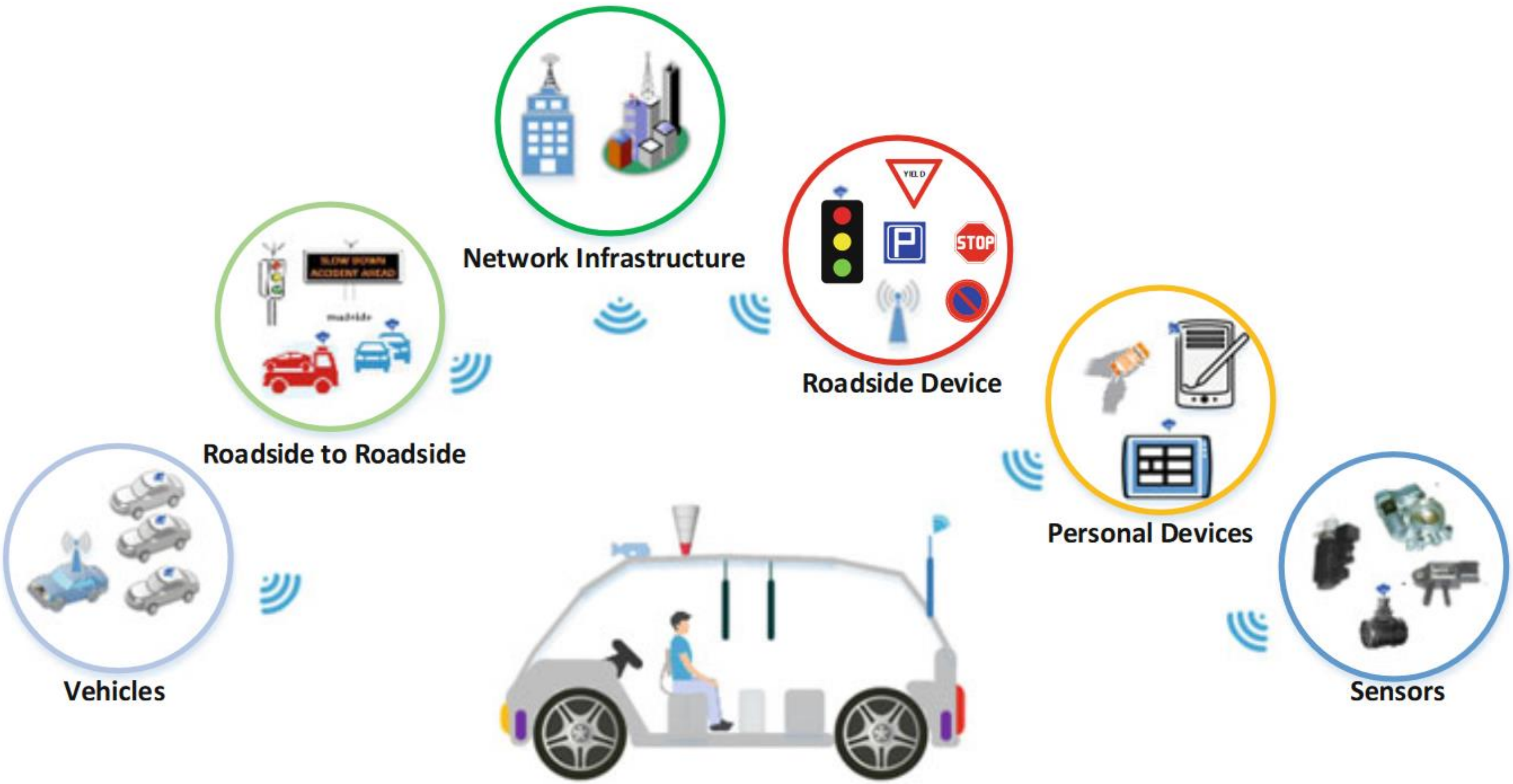
IoT Supporting HRI

Offsite Real-time Monitoring via the Internet

Offsite Control via the Internet

Offsite Alert Prompt to Humans

IoT can Help Shape the AV Industry



Interaction model for IoT-based ecosystem for an autonomous vehicle

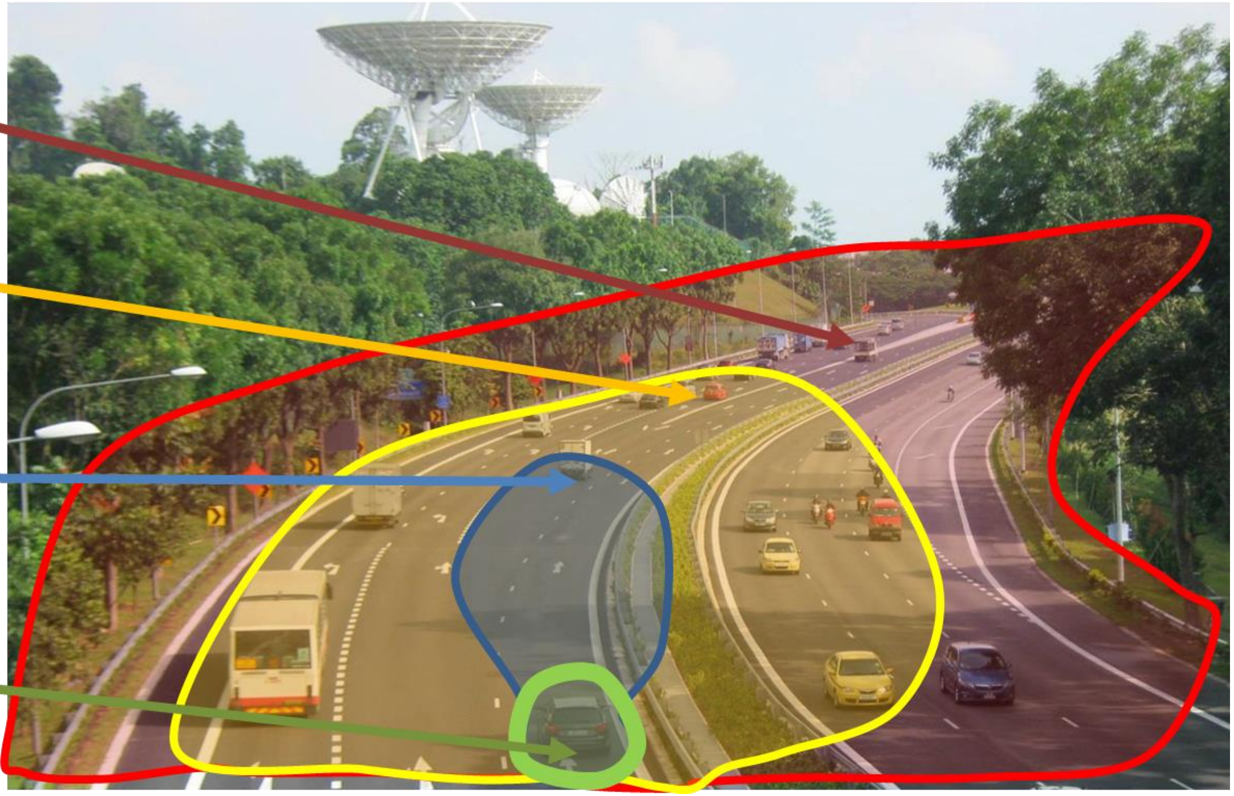
IoT can Help Shape the AV Industry

V2X
Wireless tech
>> 200 m

Radar/LiDAR
Radio waves, laser
≤ 200 m

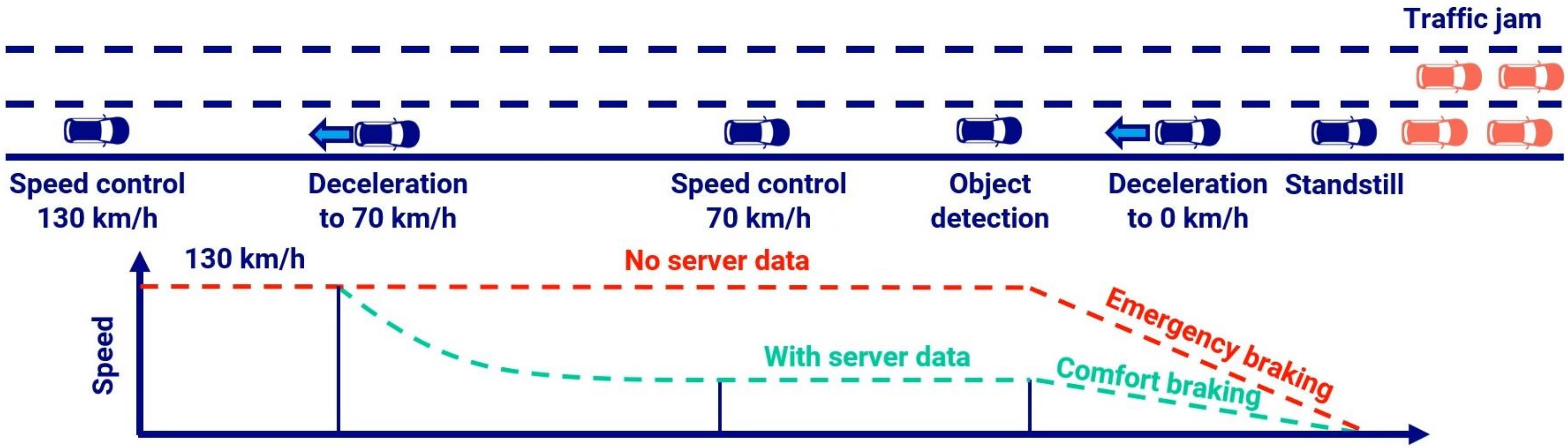
Camera
Optical, infrared
≤ 80 m

Sonar
Ultra-sound
≤ 4 m

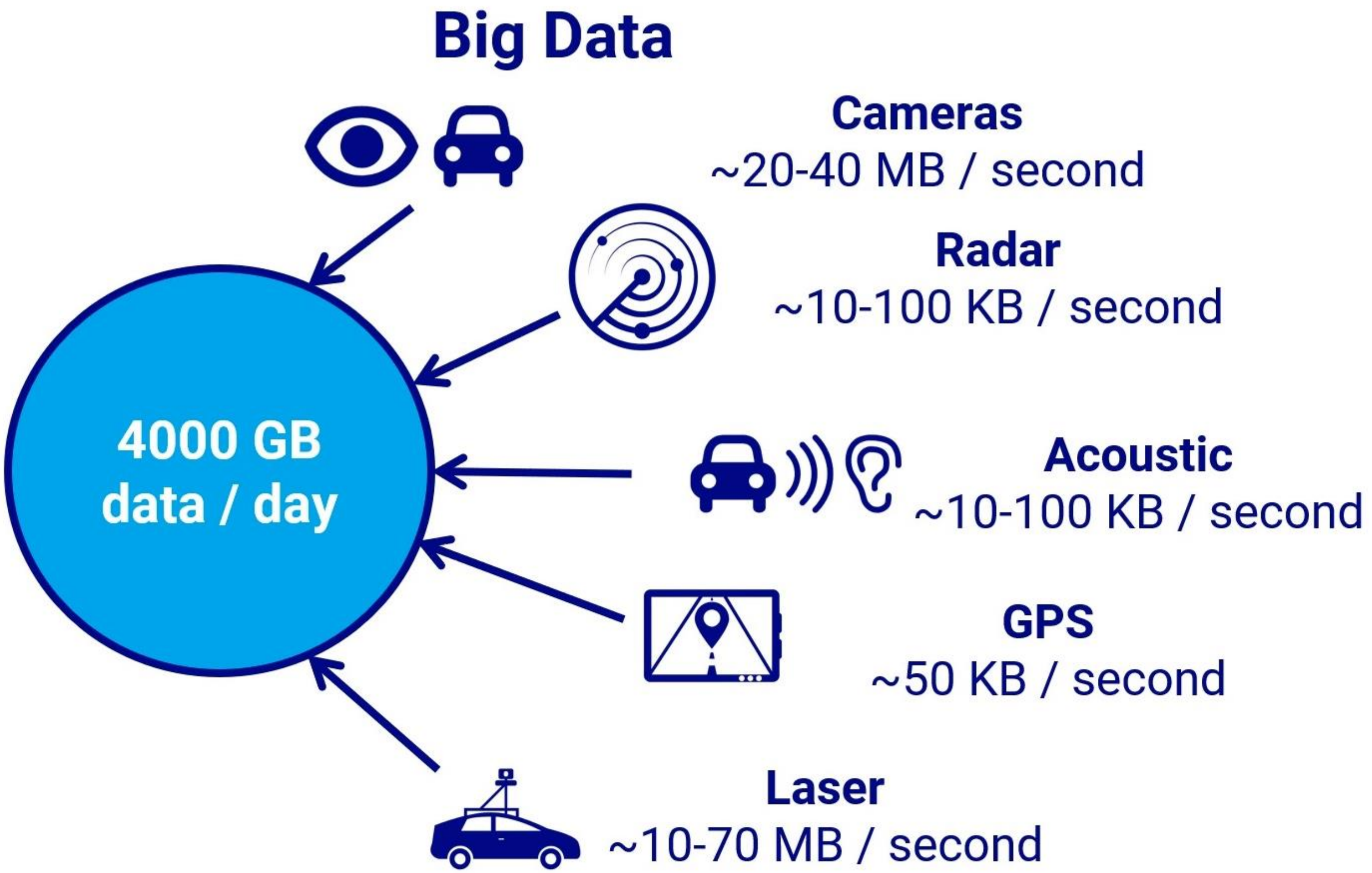


IoT can Help Shape the AV Industry

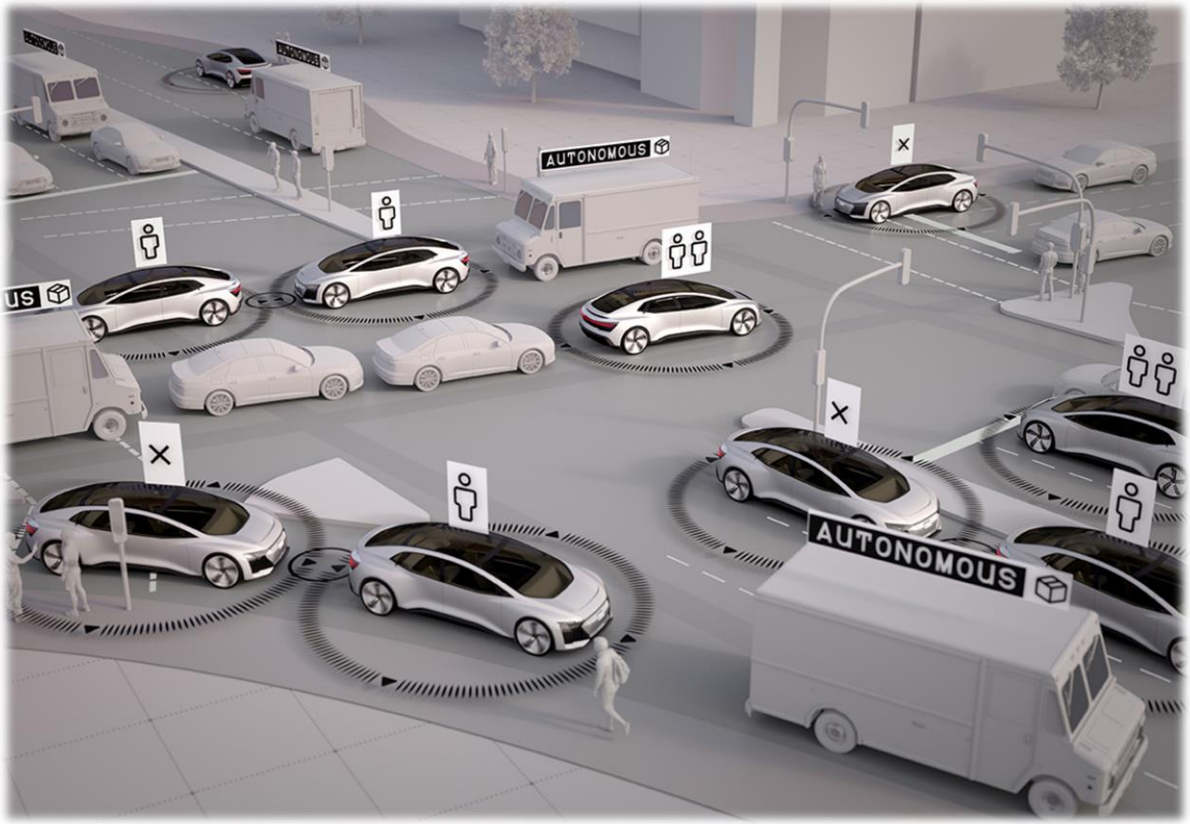
Comparison: With vs Without V2X communications



IoT can Help Shape the AV Industry



IoT can Help Shape the AV Industry



Is the current technology good enough that we can implement this concept?

Why or Why Not?

What's the solution to this problem?

ThingSpeak (Intro)

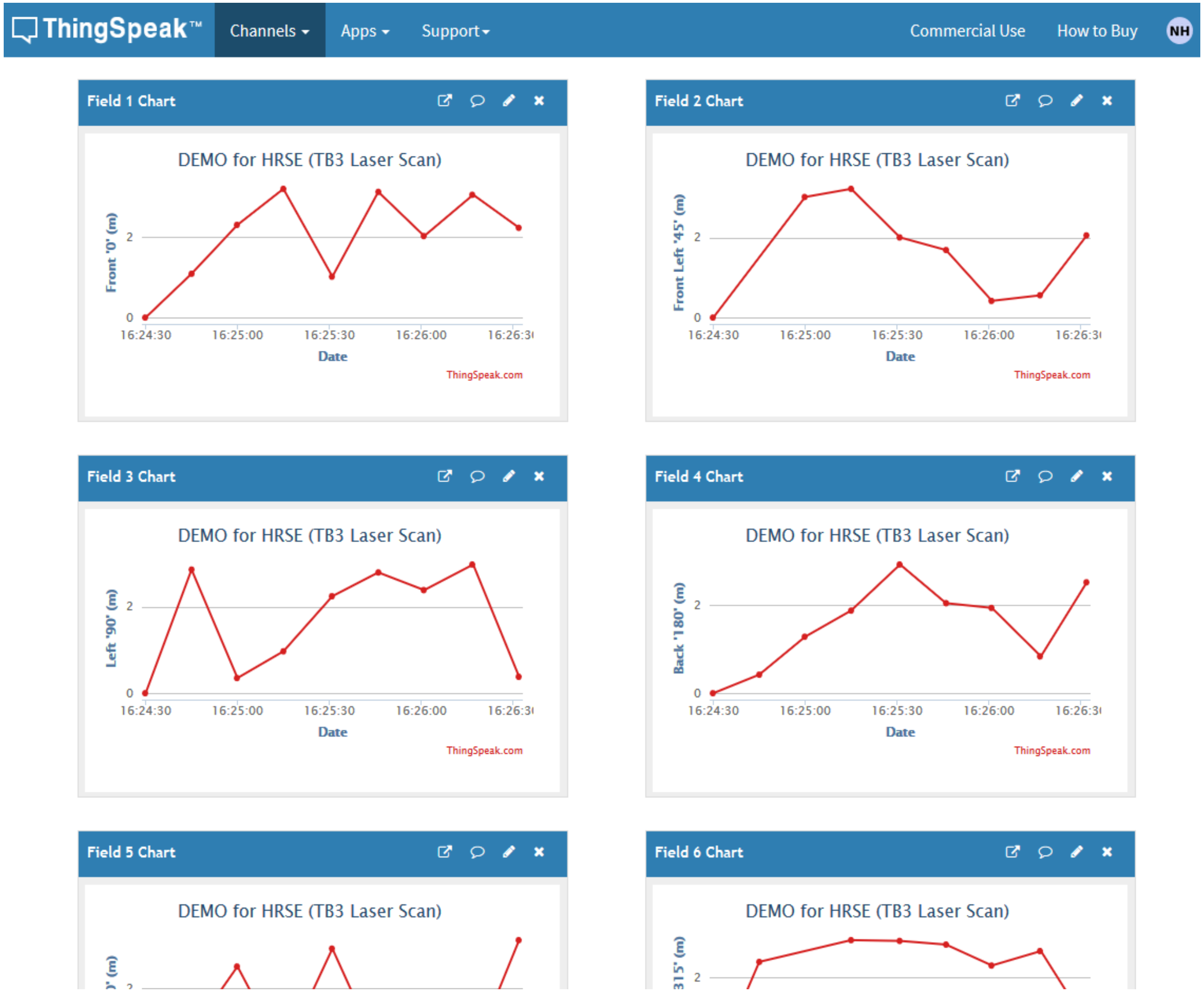
- Main features: **Collect, Analyze, Act**
- An IoT analytics platform service that allows you to **aggregate, visualize, and analyze live data streams in the cloud**
- Able to **send data to ThingSpeak from your devices (e.g. sensors within robots)**, create instant visualization of live data, and send alerts (only Twitter for this Platform)
- **Free to public** but with limitations (limited 3 million messages and 4 channels; ok for this workshop)

Access to ThingSpeak to View Data Update

- You do not need to sign up any account for this process for now
- **Follow the steps below:**
  1. Using phone or laptop, navigate to https://thingspeak.com/
  2. On top of the site, click "*Channels*", then point to and click on "*Public Channels*"
  3. Search for "Search by user ID" where there is an empty field box
  4. CopyPaste or Type my userID "**mwa0000018877967**" in this field
  5. Click "Submit" and you will see 2 boxes that you can select
  6. Depending on the Demo to be shown by the lecturer, click on the relevant demo to view the data update, i.e. click on the words "Demo for HRSE (TB3 Laser Scan)"

IoT Monitoring DEMO

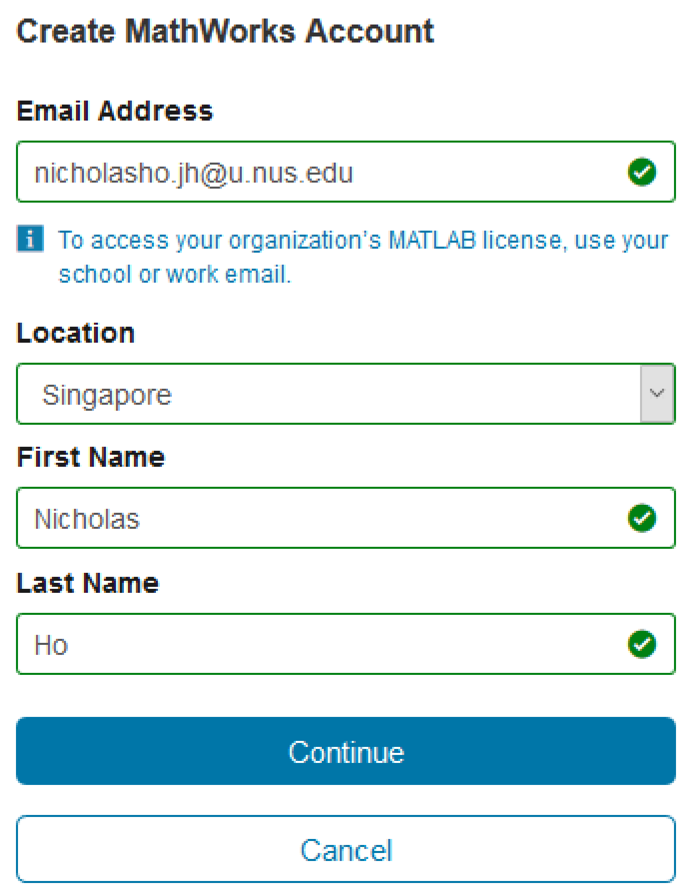
Topic to monitor for this DEMO is **TB3 Laser Scan**



ThingSpeak (SignUp)

Follow the steps below:

- Navigate to https://thingspeak.com/
- The lecturer will go through the steps on how to sign up
- Note that you will need an email at least to sign up an account (no need to be nus email)



Creating Channels on ThingSpeak:

1. Once your MathWorks account is created, click on '*Channels*' (on top bar), and then click on '*My Channels*'
2. Click on the button '*New Channel*'
3. Type in the Name of your Channel (e.g. Monitoring of TB3 Laser Scan)
4. Click on the ticks under the field section; the number of ticks depends on how many topic messages you would like to publish in this platform (you may adjust this later on if needed; to be illustrated by lecturer)
5. Once done, scroll to bottom and click '*Save Channel*'

Download & Install hrse ROS Package

Steps:

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

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

2. Git Clone the hrse package:

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

3. Build the packages in the catkin workspace:

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

4. Go to *catkin_ws/src/hrse/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
   ```

Group Project 1

IoT plays an important role within systems that involve human-robot interactions. Be it monitoring, control, big data analysis, data management and storage, emergency alerts from the robots, etc, the key advantage of IoT is that it enables us humans to communicate with the robots via the Internet, hence we do not have to be onsite or physically near the robot for these communications.

For this project, we will be focusing on the real-time and retrospective IoT monitoring aspect. Instead of the example shown previously to monitor laser scans (i.e. LiDAR readings from the TB3), this time you have to **configure an IoT system that enables us to monitor the pose parameters taken from the `/odom` topic** (i.e. the x, y, z positions and x, y, z, w orientations of the TB3). Similarly like in the demo, **use rospy and ThingSpeak in your configurations**.

Group Project 1: Ideal Result for HRSE (TB3 Pose)

Group Project 1:
Ideal Result for HRSE (TB3 Pose DEMO)

Follow the steps below:

1. Using phone or laptop, navigate to https://thingspeak.com/
2. On top of the site, click "*Channels*", then point to and click on "*Public Channels*"
3. Search for "Search by user ID" where there is an empty field box
4. CopyPaste or Type my userID "**mwa0000018877967**" in this field
5. Click "Submit" and you will see 2 boxes that you can select
6. Depending on the Demo to be shown by the lecturer, click on the relevant demo to view the data update, i.e. click on the words "Demo for HRSE (TB3 Pose)"

Group Project 1: Setup Instructions

1. Create Channel and the required details (e.g. field section) in your ThingSpeak channel
2. In the created ThingSpeak channel, take note of your Channel ID and Write API Key; you may copy and paste these details into a notepad first
3. In your Ubuntu platform, in terminal, type the following commands (1 by 1) to install the thingspeak library; you need this to publish the data to the channel(s)
   - `$ sudo apt-get update`
   - `$ sudo apt-get upgrade`
   - `$ sudo pip install thingspeak`

Group Project 1: RECAP on Sequences (Refer to README for detailed instructions)

1. Launch Gazebo in TB3 World
2. Run node to send required data to TS Channel (node to be developed in this project: Project1.py)
3. Check if your ThingSpeak Channel receives the data from your running node
4. Move TB3 around using the Teleop key node
5. The collected data should change as the TB3 moves around the map
6. Once done, export the collected data in CSV

Instructions

This is a group project. Each group submits one zip file of all your codes/files (i.e. py and CSV) into LumiNUS at the end of the workshop

A123456_A234567_A345678_P1.zip

- Download all files in the directory **/workshops/day1** for reference codes
- Refer to the README file for instructions

OPTIONAL TASKS

PHYSICAL TB3 TEST, IOT MONITORING OF IMU, IOT CONTROL OF TB3

(A) Physical TB3 Test
RECAP on Sequences
(Refer to README for detailed instructions)

1. Do the OpenCR Setup (if have not done so)
2. Run roscore and do bring up procedures
3. Run node to send required data to TS Channel (i.e. Project1.py)
4. Check if your ThingSpeak Channel receives the data from your running node
5. Move TB3 around using the Teleop key node
6. The collected data should change as the TB3 moves around the map

(B) IoT Monitoring of IMU
Just for practice ONLY if you have time

- Create a node (i.e. imu.py) that is able to send data to ThingSpeak for monitoring purposes
- You may create a new channel for this
- **Interested variables:** Angular Velocities and Linear Accelerations at the various directions
- **Hint:** you may use rqt's topic monitor to guide you to understand which topic and its respective parameters are relevant

(C) IoT Control

- Apart from IoT Monitoring, IoT Control enables us to **control the robot at an offsite location**
- We will explore using an Android App (i.e. **ROS Control**) for this example
- Note that you will require an **Android Device (i.e. phone, tablet)** to do this
- Although this example is not considered as a complete IoT system (using TCP/IP), it can be easily configured to be one

(C) IoT Control

Setup:

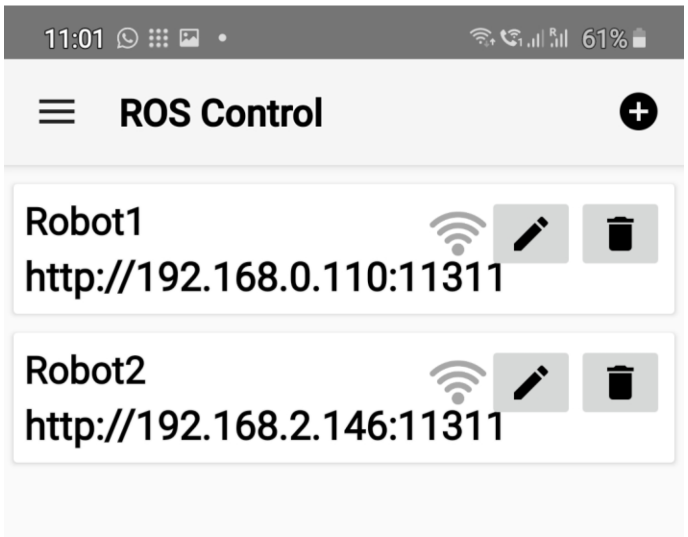
1. Download and install the following app in your Android device: https://play.google.com/store/apps/details?id=com.robotca.ControlApp
2. If you are using VirtualBox for your platform, go to Settings, Network, then change from ‘NAT’ to ‘Bridged Adapter’ mode
3. Ensure both your device and Ubuntu is connected to the same router
4. Within your Ubuntu, open terminal and type `$ ifconfig` to find out your IP address (i.e. 192.168.X.XXX)
5. Type command `$ nano ~/.bashrc` and press `alt+/` to go to end of line or you can scroll manually to the end of the line
6. Modify the IP address under `ROS_MASTER_URI` and `ROS_HOSTNAME` by replacing `localhost` with 192.168.X.XXX

Setup (Cont):

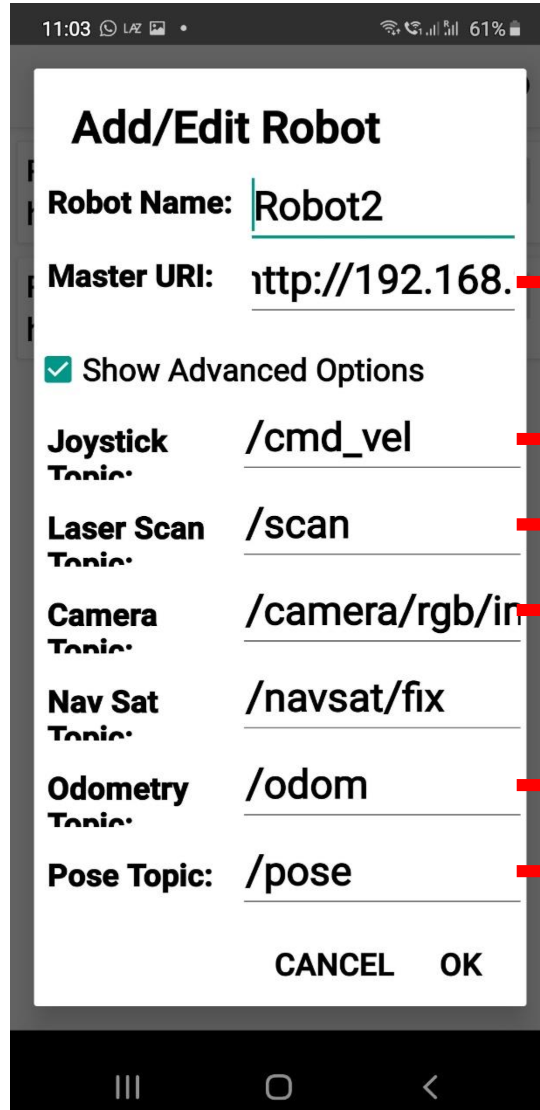
7. Once done, type ^X to exit and source the bashrc with `$ source ~/.bashrc`
8. Once done, go to your downloaded app and add a robot (Robot name can be anything you want)
9. Refer to next slide for the other details to fill in (i.e. Master URI, Topic Names)

(C) IoT Control

Setup (Cont):



Can be used for both Virtual and Physical Robot; note that camera topic is different for virtual and physical robots



https://192.168.X.XXX:11311

/cmd_vel

/scan

/camera/rgb/image_raw

/odom

/pose

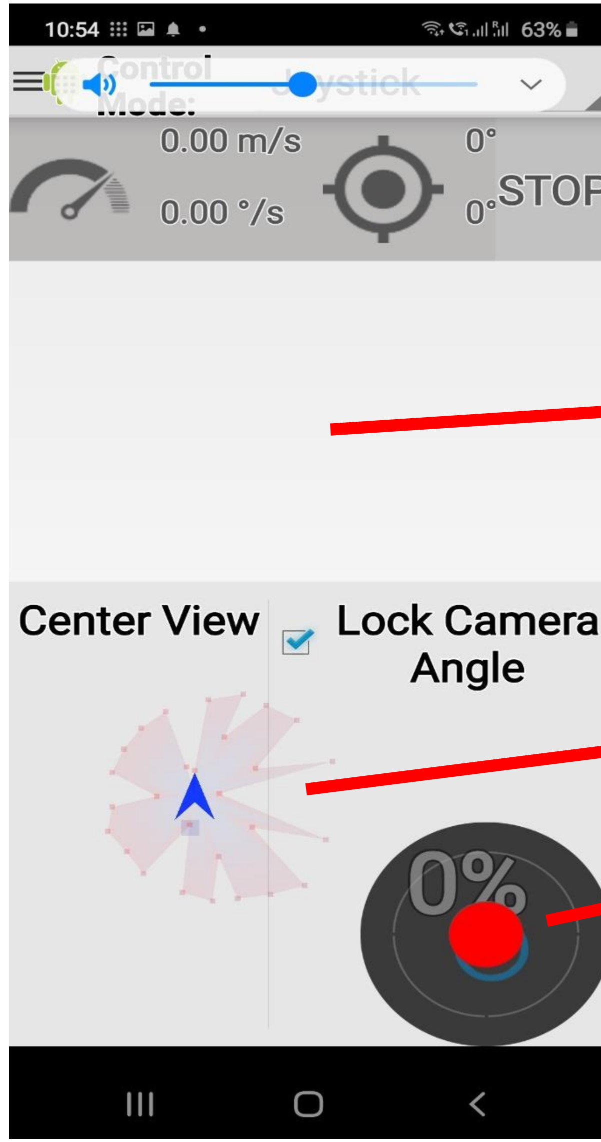
Execution (for Virtual TB3):

1. Launch Gazebo in TurtleBot3 world
2. Launch ROS Control Android App and under home, click on the robot that you have created (e.g. Robot1, Robot2)
3. A User Interface will appear which allows you to control the TB3 with the joystick (next slide)

Take note that the app is very buggy; unable to load the camera data and will occasionally break connection. It is still not robust enough

(C) IoT Control

Execution (for Virtual TB3):



Interface to visualize the camera data (unable to load)

Interface to visualize the scans and TB3 pose

Joystick to move the TB3

THANK YOU

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