



The Duckietown Book



The last version of this book and other documents are available at the URL
<http://book.duckietown.org/>

TABLE OF CONTENTS

Part 1 - The Duckietown project..... 7

Chapter 1 - What is Duckietown?..... 8

 Section 1.1 - Goals and objectives..... 8

 Section 1.2 - Results obtained so far 8

 Section 1.3 - Learn about the platform..... 8

 Section 1.4 - Learn about the educational experience 8

 Section 1.5 - Learn about the platform..... 8

Chapter 2 - Duckietown history and future..... 9

 Section 2.1 - The beginnings of Duckietown 9

 Section 2.2 - Duckietown around the world 9

 Section 2.3 - Coming up..... 9

Chapter 3 - First steps 10

 Section 3.1 - How to get started 10

 Section 3.2 - Duckietown for instructors 10

 Section 3.3 - Duckietown for self-guided learners 10

 Section 3.4 - Introduction for companies..... 10

 Section 3.5 - How to keep in touch 10

 Section 3.6 - How to contribute 10

Chapter 4 - Frequently Asked Questions..... 11

 Section 4.1 - General questions..... 11

 Section 4.2 - FAQ by students / independent learners 11

 Section 4.3 - FAQ by instructors 11

Part 2 - Software carpentry..... 12

Chapter 5 - Linux 13

 Section 5.1 - Background reading..... 13

 Section 5.2 - Ubuntu packaging..... 13

 Section 5.3 - Measuring resource usage 13

 Section 5.4 - How to burn an image to an SD card 14

Chapter 6 - Networking..... 16

 Section 6.1 - Background reading..... 16

 Section 6.2 - Visualizing information about the network 16

Chapter 7 - Wireless networks..... 17

Chapter 8 - Compilers..... 18

Chapter 9 - Accessing computers using SSH..... 19

 Section 9.1 - Background reading 19

 Section 9.2 - Installation of SSH..... 19

 Section 9.3 - Local configuration 19

 Section 9.4 - How to login with SSH and a password..... 19

 Section 9.5 - Creating an SSH keypair 20

 Section 9.6 - How to login without a password 21

 Section 9.7 - Fixing SSH Permissions..... 22

 Section 9.8 - SCP..... 22

 Section 9.9 - RSync..... 22

Chapter 10 - Editors 23

 Section 10.1 - VIM 23

Chapter 11 - Source code control with Git..... 24

 Section 11.1 - Background reading..... 24

 Section 11.2 - Installation 24

 Section 11.3 - Setting up global configurations for Git 24

 Section 11.4 - Git tips 24

 Section 11.5 - Git troubleshooting 24

Chapter 12 - Shells 26

Section 12.1 - Byobu	26
Chapter 13 - Other things to know	27
Section 13.1 - Markdown	27
Part 3 - Preliminaries	28
Chapter 14 - Linear algebra	29
Chapter 15 - Probability basics	30
Chapter 16 - Dynamics	31
Part 4 - Duckiebot setup	32
Chapter 17 - Acquiring the parts for the Duckiebot	33
Section 17.1 - Duckiebot configurations	33
Section 17.2 - Bill of materials	33
Section 17.3 - Chassis	33
Section 17.4 - Raspberry PI 3	34
Section 17.5 - Camera	34
Chapter 18 - Soldering boards	35
Chapter 19 - Assembling the Duckiebot	36
Chapter 20 - Reproducing the image	37
Section 20.1 - Download and uncompress the Ubuntu Mate image	37
Section 20.2 - Burn the image to an SD card	37
Section 20.3 - Raspberry PI Config	38
Section 20.4 - Install packages	38
Section 20.5 - Install Edimax driver	39
Section 20.6 - Install ROS	39
Section 20.7 - Wireless configuration (old version)	39
Section 20.8 - Wireless configuration	40
Section 20.9 - SSH server config	41
Section 20.10 - Create swap Space	41
Section 20.11 - Passwordless sudo	42
Section 20.12 - Ubuntu user configuration	42
Chapter 21 - Installing Ubuntu on laptops	44
Section 21.1 - Install Ubuntu	44
Section 21.2 - Install useful software	44
Section 21.3 - Install ROS	45
Section 21.4 - Other suggested software	45
Section 21.5 - Passwordless sudo	45
Section 21.6 - SSH and Git setup	45
Chapter 22 - Setup Github access	47
Section 22.1 - Create a Github account	47
Section 22.2 - Become a member of the Duckietown organization	47
Section 22.3 - Add a public key to Github	47
Chapter 23 - Duckiebot Initialization	49
Section 23.1 - Acquire and burn the image	49
Section 23.2 - Turn on the Duckiebot	49
Section 23.3 - Connect the Duckiebot to a network	50
Section 23.4 - Ping the Duckiebot	50
Section 23.5 - SSH to the Duckiebot	50
Section 23.6 - (For D17-C1) Configure the robot-generated network	50
Section 23.7 - Setting up wireless network configuration	51
Section 23.8 - Update the system	52
Section 23.9 - Give a name to the Duckiebot	52
Section 23.10 - Change the hostname	52
Section 23.11 - Create your user	53
Section 23.12 - Other customizations	54
Section 23.13 - Hardware check: camera	54
Chapter 24 - Software setup and RC remote control	56
Section 24.1 - Clone the Duckietown repository	56
Section 24.2 - Set up ROS environment on the Duckiebot	56

Section 24.3 - Add your vehicle to the machines file	57
Section 24.4 - Test that the joystick is detected	57
Section 24.5 - Run the joystick demo	58
Section 24.6 - The proper shutdown procedure for the Raspberry PI.....	59
Chapter 25 - Reading from the camera	60
Section 25.1 - Check the camera hardware.....	60
Section 25.2 - Create two windows.....	60
Section 25.3 - First window: launch the camera nodes	60
Section 25.4 - Second window: view published topics.....	61
Chapter 26 - RC control launched remotely	62
Section 26.1 - Two ways to launch a program	62
Section 26.2 - Make sure that you can log in from the laptop.....	62
Section 26.3 - Download and setup Software repository on the laptop	62
Section 26.4 - Edit the machines files on your laptop	62
Section 26.5 - Start the demo.....	63
Section 26.6 - Watch the program output using rqt_console.....	63
Section 26.7 - Troubleshooting.....	63
Chapter 27 - RC+camera remotely	64
Section 27.1 - Assumptions	64
Section 27.2 - Terminal setup	64
Section 27.3 - First window: launch the joystick demo.....	64
Section 27.4 - Second window: launch the camera nodes.....	65
Section 27.5 - Third window: view data flow	65
Section 27.6 - Fourth window: visualize the image using rviz	65
Section 27.7 - Proper shutdown procedure.....	65
Chapter 28 - Interlude: Ergonomics	67
Section 28.1 - set_ros_master.sh.....	67
Section 28.2 - SSH aliases	67
Chapter 29 - Wheel calibration	68
Chapter 30 - Camera calibration	69
Chapter 31 - Taking a log	70
Chapter 32 - D17-1 (LEDs) parts	71
Chapter 33 - D17-1 (LEDs) assembly	72
Chapter 34 - D17-1 (LEDs) setup	73
 Part 5 - Duckietowns	 74
Chapter 35 - Duckietown parts	75
Chapter 36 - Duckietown Assembly	76
Chapter 37 - The Duckietown specification	77
Section 37.1 - Topology	77
Section 37.2 - Signs placement	77
Chapter 38 - Traffic lights	78
 Part 6 - Developing software	 79
Chapter 39 - Python	80
Section 39.1 - Background reading.....	80
Section 39.2 - Python virtual environments	80
Section 39.3 - Useful libraries.....	80
Chapter 40 - Introduction to ROS	81
Section 40.1 - Install ROS	81
Section 40.2 - rqt_console	81
Section 40.3 - roslaunch.....	81
Section 40.4 - rviz.....	81
Section 40.5 - rostopic.....	82
Chapter 41 - What the duck!	83
Section 41.1 - Adding more tests to what-the-duck	83
Section 41.2 - Tests already added	83
Section 41.3 - List of tests to add	84
Chapter 42 - How to create a ROS package	85

Section 42.1 - Conforming ROS package checklist	85
Chapter 43 - Integrate package in the architecture.....	86
Chapter 44 - Creating unit tests	87
Part 7 - Modules	88
Chapter 45 - Module template	89
Chapter 46 - Autonomy overview	90
Section 46.1 - Perception, planning, control.....	90
Chapter 47 - Autonomy architectures	91
Chapter 48 - Representations.....	92
Chapter 49 - Software architectures and middlewares.....	93
Chapter 50 - Modern signal processing.....	94
Chapter 51 - Basic Kinematics	95
Chapter 52 - Basic Dynamics	96
Chapter 53 - Odometry Calibration	97
Chapter 54 - Computer vision basics.....	98
Chapter 55 - Illumination invariance	99
Chapter 56 - Line Detection	100
Chapter 57 - Feature extraction	101
Chapter 58 - Place recognition	102
Chapter 59 - Filtering 1	103
Chapter 60 - Filtering 2.....	104
Chapter 61 - Mission planning.....	105
Chapter 62 - Planning in discrete domains	106
Chapter 63 - Motion planning.....	107
Chapter 64 - RRT.....	108
Chapter 65 - Feedback control	109
Chapter 66 - PID Control.....	110
Chapter 67 - MPC Control.....	111
Chapter 68 - Object detection.....	112
Chapter 69 - Object classification	113
Chapter 70 - Object tracking	114
Chapter 71 - Reacting to obstacles.....	115
Chapter 72 - Semantic segmentation	116
Chapter 73 - Text recognition.....	117
Chapter 74 - SLAM - Problem formulation	118
Chapter 75 - SLAM - Broad categories	119
Chapter 76 - VINS	120
Chapter 77 - Advanced place recognition.....	121
Chapter 78 - Fleet level planning (placeholder).....	122
Chapter 79 - Fleet level planning (placeholder).....	123
Part 8 - How to contribute.....	124
Chapter 80 - Accounts	125
Section 80.1 - Complete list of accounts.....	125
Section 80.2 - For Fall 2017	125
Section 80.3 - For other contributors.....	125
Chapter 81 - Contributing to the documentation	126
Section 81.1 - Where the documentation is.....	126
Section 81.2 - Editing links.....	126
Section 81.3 - Comments	126
Section 81.4 - Installing dependencies for compiling the documentation	126
Section 81.5 - Extra dependencies for compiling the PDF version.....	127
Section 81.6 - Troubleshooting installation problems	128
Section 81.7 - Compiling the documentation	128
Section 81.8 - Deploying the documentation	129
Section 81.9 - In summary: the workflow.....	129
Chapter 82 - Features of the documentation writing system.....	130
Section 82.1 - Embedded LaTeX	130

Section 82.2 - Other interesting features.....	130
Section 82.3 - Character escapes	131
Section 82.4 - Troubleshooting.....	131
Chapter 83 - Documentation style guide	133
Section 83.1 - General guidelines for technical writing.....	133
Section 83.2 - Style guide for the Duckietown documentation	133
Section 83.3 - Writing command lines	133
Section 83.4 - Frequently misspelled words	134
Section 83.5 - Other conventions	134
Section 83.6 - Troubleshooting sections.....	134
Part 9 - Fall 2017.....	135
Chapter 84 - General remarks.....	136
Section 84.1 - The rules of Duckietown	136
Section 84.2 - Synchronization between classes.....	136
Section 84.3 - Accounts for students	136
Section 84.4 - Accounts for all instructors and TAs.....	136
Section 84.5 - Other accounts for organizers.....	137
Section 84.6 - Additional information for ETH Zürich students.....	137
Section 84.7 - Additional information for UdeM students.....	137
Section 84.8 - Additional information for TTIC students	137
Section 84.9 - Additional information for NCTU students	137
Chapter 85 - Project proposals	138
Chapter 86 - Template of a project.....	139
Part 10 - Fall 2017 student progression	140
Chapter 87 - Milestone: ROS node working.....	141
Chapter 88 - Homework: Take and process a log.....	142
Chapter 89 - Milestone: Calibrated robot.....	143
Chapter 90 - Homework: Camera geometry.....	144
Chapter 91 - Milestone: Illumination invariance.....	145
Chapter 92 - Homework: Place recognition	146
Chapter 93 - Milestone: Lane following.....	147
Chapter 94 - Homework: localization	148
Chapter 95 - Milestone: Navigation.....	149
Chapter 96 - Homework: group forming	150
Chapter 97 - Milestone: Ducks in a row.....	151
Chapter 98 - Homework: Comparison of PID.....	152
Chapter 99 - Homework: RRT	153
Chapter 100 - Caffè tutorial.....	154
Chapter 101 - Milestone: Object Detection.....	155
Chapter 102 - Homework: Object Detection	156
Chapter 103 - Milestone: Semantic perception	157
Chapter 104 - Homework: Semantic perception	158
Chapter 105 - Milestone: Reacting to obstacles.....	159
Chapter 106 - Homework: Reacting to obstacles	160
Chapter 107 - Milestone: SLAM demo	161
Chapter 108 - Homework: SLAM.....	162
Chapter 109 - Milestone: fleet demo	163
Chapter 110 - Homework: fleet.....	164
Section 110.1 - Checklist for students	164
Section 110.2 - Checklist for TAs	164
Chapter 111 - Bibliography.....	165
Part 11 - Drafts or pieces to remove.....	166
Chapter 112 - Laptop setup	167
Section 112.1 - Setup passwordless SSH to log in using the ubuntu user	167

PART 1

The Duckietown project

CHAPTER 1

What is Duckietown?

1.1. Goals and objectives

Duckietown is a robotics education and outreach effort.

The most tangible goal of the project is to provide a low-cost educational platform for learning autonomy, consisting of the Duckiebots, an autonomous robot, and the Duckietowns, the infrastructure in which the Duckiebots navigate.

However, we focus on the *learning experience* as a whole, by providing a set of modules teaching plans and other guides, as well as a curated role-play experience.

We have two targets:

1. For **instructors**, we want to create a “class-in-a-box” that allows to offer a modern and engaging learning experience. Currently, this is feasible at the advanced undergraduate and graduate level, though in the future we would like to present the platform as multi-grade experiences.
2. For **self-guided learners**, we want to create a “self-learning experience”, that allows to go from zero knowledge of robotics to graduate-level understanding.

In addition, the Duckietown platform has been used as a research platform.

1.2. Results obtained so far

While we are at the early phases of the project, many people have been using the materials in the past year.

1.3. Learn about the platform

The best way to get a sense of how the platform looks is to watch these videos. They show off the capabilities of the platform.

This video is part of the Red Hat documentary:

1.4. Learn about the educational experience

These papers present a more formal description of the technical side of the project as well as the educational side.

This paper [1] describes the course design for Duckietown: learning objectives, teaching methods, etc.

This video is a Duckumentary about the first version of the class, during Spring 2016. The Duckumentary was shot by Chris Welch.

1.5. Learn about the platform

The paper [2] describes the Duckiebot and its software. With 29 authors, we made the record for a robotics conference.

CHAPTER 2

Duckietown history and future

| Assigned to: Liam

2.1. The beginnings of Duckietown

Duckietown started as an MIT class during Spring 2016.

2.2. Duckietown around the world

1) Duckietown High School

2.3. Coming up

In 2017, the class will be offered contemporaneously at:

- ETH Zurich
- University of Montreal
- University of Chicago

as well as:

CHAPTER 3

First steps

3.1. How to get started

If you are an instructor, please jump to [Section 3.2](#).

If you are a self-guided learner, please jump to [Section 3.3](#).

If you are a company, and interested in working with Duckietown, please jump to [Section 3.4](#).

3.2. Duckietown for instructors

3.3. Duckietown for self-guided learners

3.4. Introduction for companies

3.5. How to keep in touch

3.6. How to contribute

CHAPTER 4

Frequently Asked Questions

4.1. General questions

Q: What is Duckietown?

Duckietown is a low-cost educational and research platform.

Q: Is Duckietown free to use?

Yes. All materials are released according to an open source license.

Q: Is everything ready?

Not quite! Please [sign up to our mailing list](#) to get notified when things are a bit more ready.

Q: How can I start?

See the next section, Getting started.

Q: How can I help?

If you would like to help actively, please email duckietown@mit.edu.

4.2. FAQ by students / independent learners

Q: I want to build my own Duckiebot. How do I get started?

4.3. FAQ by instructors

Q: How large a class can it be? I teach large classes.

Q: What is the budget for the robot?

Q: I want to teach a Duckietown class. How do I get started?

Please get in touch with us at duckietown@mit.edu. We will be happy to get you started and sign you up to the Duckietown instructors mailing list.

Q: Why the duckies?

Compared to other educational robotics projects, the presence of the duckies is what makes this project stand out. Why the duckies?

We want to present robotics in an accessible and friendly way.

PART 2

Software carpentry

This part describes things that you should know about UNIX/Linux environments. Please read the “background reading” section before you start, while the rest can be used as a reference.

Documentation writers: please make sure that every command used has a section in these chapters.

CHAPTER 5

Linux

| Assigned to: Andrea

5.1. Background reading

- UNIX
- Linux
- free software; open source software.

5.2. Ubuntu packaging

1) apt install

2) apt update

3) apt dist-upgrade

5.3. Measuring resource usage

1) pgrep

2) Testing SD Card and disk speed

Test SD Card (or any disk) speed using the following commands, which write to a file called `[filename]`.

```
$ dd if=/dev/zero of=[filename] bs=500K count=1024
$ sync
$ echo 3 | sudo tee /proc/sys/vm/drop_caches
$ dd if=[filename] of=/dev/null bs=500K count=1024
$ rm [filename]
```

Note the sync and the echo command are very important.

Example results:

```
524288000 bytes (524 MB, 500 MiB) copied, 30.2007 s, 17.4 MB/s
524288000 bytes (524 MB, 500 MiB) copied, 23.3568 s, 22.4 MB/s
```

That is write 17.4 MB/s, read 22 MB/s.

3) Measuring CPU usage using `htop`

You can use `htop` to monitor CPU usage.

```
$ sudo apt install htop
```

4) Measuring I/O usage using `iostat`

```
$ sudo apt install iostat
```

5.4. How to burn an image to an SD card

Requires:

- A blank SD card.
- An image file to burn.
- An Ubuntu computer with an SD reader.

Results:

- A burned image.

1) Finding your device name for the SD card

First, find out what is the device name for the SD card.

Insert the SD Card in the slot.

Run the command:

```
$ sudo fdisk -l
```

Find your device name, by looking at the sizes.

For example, the output might contain:

```
Disk /dev/mmcblk0: 14.9 GiB, 15931539456 bytes, 31116288 sectors
Units: sectors of 1 * 512 = 512 bytes
Sector size (logical/physical): 512 bytes / 512 bytes
I/O size (minimum/optimal): 512 bytes / 512 bytes
```

In this case, the device is `/dev/mmcblk0`. That will be the `[device]` in the next commands.

You may see `/dev/mmcblk0pX` or a couple of similar entries for each partition on the card, where `X` is the partition number. If you don't see anything like that, take out the SD card and run the command again and see what disappeared.

2) Unmount partitions

Before proceeding, unmount all partitions.

Run `df -h`. If there are partitions like `/dev/mmcblk0p[n]`, then unmount each of them. For example:

```
laptop $ sudo umount /dev/mmcblk0p1
laptop $ sudo umount /dev/mmcblk0p2
```

3) Burn the image

Now that you know that the device is `[device]`, you can burn the image to disk.

Let the image file be `[image file]`.

Burn the image using the command `dd`:

```
laptop $ sudo dd of=[device] if=[image file] status=progress bs=4M
```

Note: Use the name of the device, without partitions. i.e., `/dev/mmcblk0`, not `/dev/mmcblk0pX`.

CHAPTER 6

Networking

| Assigned to: Andrea

6.1. Background reading

Here are some background reading about networking and networking in Linux:

Make sure that you know:

- what are IP addresses
- what are subnets
- how DNS works
- how `.local` names work
- ...

A short reference follows.

6.2. Visualizing information about the network

1) ping

2) ifconfig

```
$ ifconfig
```


CHAPTER 7

Wireless networks

1) `iwlist`

What wireless networks do I have around?

```
$ sudo iwlist [interface] scan | grep SSID
```

Does the interface support 5 GHz channels?

```
$ sudo iwlist [interface] freq
```

Example output:

```
wlx74da38c9caa0 20 channels in total; available frequencies :  
Channel 01 : 2.412 GHz  
Channel 02 : 2.417 GHz  
Channel 03 : 2.422 GHz  
Channel 04 : 2.427 GHz  
Channel 05 : 2.432 GHz  
Channel 06 : 2.437 GHz  
Channel 07 : 2.442 GHz  
Channel 08 : 2.447 GHz  
Channel 09 : 2.452 GHz  
Channel 10 : 2.457 GHz  
Channel 11 : 2.462 GHz  
Channel 36 : 5.18 GHz  
Channel 40 : 5.2 GHz  
Channel 44 : 5.22 GHz  
Channel 48 : 5.24 GHz  
Channel 149 : 5.745 GHz  
Channel 153 : 5.765 GHz  
Channel 157 : 5.785 GHz  
Channel 161 : 5.805 GHz  
Channel 165 : 5.825 GHz  
Current Frequency:2.437 GHz (Channel 6)
```

Note that in this example only *some* 5Ghz channels are supported (36, 40, 44, 48, 149, 153, 157, 161, 165); for example, channel 38, 42, 50 are not supported. This means that you need to set up the router not to use those channels.

CHAPTER 8

Compilers

| Assigned to: Andrea

CHAPTER 9

Accessing computers using SSH

Assigned to: Andrea

9.1. Background reading

- Encryption
- Public key authentication

9.2. Installation of SSH

This installs the client:

```
$ sudo apt install ssh
```

This installs the server:

This enables the server:

9.3. Local configuration

The SSH configuration as a client is in the file

```
~/.ssh/config
```

Create the directory with the right permissions:

```
$ mkdir ~/.ssh  
$ chmod 0700 ~/.ssh
```

Then add the following lines:

```
HostKeyAlgorithms ssh-rsa
```

The reason is that Paramiko, used by `roslaunch`, [does not support the ECDSA keys](#).

9.4. How to login with SSH and a password

To log in to a remote computer `[remote]` with user `[remote-user]`, use:

```
$ ssh [remote-user]@[remote]
```

1) Troubleshooting

Symptom: “Offending key error”.

If you get something like this:

```
Warning: the ECDSA host key for [...] differs from the key for the IP address '[...]'  
Offending key for IP in /home/[user]/.ssh/known_hosts:[line]
```

then remove line [line] in ~/.ssh/known_hosts.

9.5. Creating an SSH keypair

This is a step that you will repeat twice: once on the Duckiebot, and once on your laptop.

The program will prompt you for the filename on which to save the file.

Use the convention

```
/home/[username]/.ssh/[username]@[host name]
/home/[username]/.ssh/[username]@[host name].pub
```

where:

- [username] is the current user name that you are using (ubuntu or your chosen one);
- [host name] is the name of the host (the Duckiebot or laptop);

An SSH key can be generated with the command:

```
$ ssh-keygen -h
```

The session output will look something like this:

```
Generating public/private rsa key pair.
Enter file in which to save the key (/home/[username]/.ssh/id_rsa):
```

At this point, tell it to choose this file:

```
/home/[username]/.ssh/[username]@[host name]
```

Then:

```
Enter passphrase (empty for no passphrase):
```

Press enter; you want an empty passphrase.

```
Enter same passphrase again:
```

Press enter.

```
Your identification has been saved in /home/[username]/.ssh/[username]@[host name]
Your public key has been saved in /home/[username]/.ssh/[username]@[host name].pub
The key fingerprint is:
[XX:XX:XX:XX:XX:XX:XX:XX:XX:XX:XX:XX:XX:XX:XX:XX] [username]@[host name]
The key's randomart image is:
+--[ RSA 2048 ]-----+
|      .                |
| o o .                |
| o = o . o            |
| B . . * o            |
| S o 0                |
| o o . E              |
| o o o                |
| o +                  |
| .. .                 |
+-----+

```

Note that the program created two files.

The file that contains the private key is

```
/home/[username]/.ssh/[username]@[host name]
```

The file that contains the public key has extension `.pub`:

```
/home/[username]/.ssh/[username]@[host name].pub
```

Next, tell SSH that you want to use this key.

Make sure that the file `~/.ssh/config` exists:

```
$ touch ~/.ssh/config
```

Add a line containing

```
IdentityFile [PRIVATE_KEY_FILE]
```

(using the filename for the private key).

Check that the config file is correct:

```
$ cat ~/.ssh/config
[...]
IdentityFile [PRIVATE_KEY_FILE]
[...]
```

9.6. How to login without a password

Assumptions:

- You have two computers, called “[local]” and “[remote]”, with users “[local-user]” and “[remote-user]”.
- The two computers are on the same network.
- You have created a keypair for [local-user] on [local].

→ This procedure is described in [Section 9.5](#).

Results:

- From the [local] computer, [local-user] will be able to log in to [remote] computer without a password.

First, connect the two computers to the same network, and make sure that you can ping [remote] from [local]:

```
[local] $ ping [remote].local
```

Do not continue if you cannot do this successfully.

If you have created a keypair for [local-user], you will have a public key in this file on the [local] computer:

```
/home/[local-user]/.ssh/[local-user]@[local].pub
```

This file is in the form:

```
ssh-rsa [long list of letters and numbers] [local-user]@[local]
```

You will have to copy the contents of this file on the [remote] computer, to tell it that this key is authorized.

On the [remote] computer, edit or create the file:

```
/home/[remote-user]/.ssh/authorized_keys
```

and add the entire line as above containing the public key.

Now, from the [local] computer, try to log in into the [remote] one:

```
[local] $ ssh [remote-user]@[remote]
```

This should succeed, and you should not be asked for a password.

9.7. Fixing SSH Permissions

Sometimes, SSH does not work because you have the wrong permissions on some files.

In doubt, these lines fix the permissions for your .ssh directory.

```
$ chmod 0700 ~/.ssh  
$ chmod 0700 ~/.ssh/*
```

9.8. SCP

1) Download a file with SCP

9.9. RSync

CHAPTER 10

Editors

| Assigned to: Andrea

10.1. VIM

The editor to choose is `vi`, or more precisely, `vim` (improved `vi`).

Install like this:

```
$ sudo apt install vim
```

Documentation:

- [A VIM tutorial](#)

CHAPTER 11

Source code control with Git

| Assigned to: Andrea

11.1. Background reading

- Git
- GitFlow

11.2. Installation

The basic Git program is installed using

```
$ sudo apt install git
```

Additional utilities for git are installed using:

```
$ sudo apt install git-extras
```

This include the git-ignore utility.

11.3. Setting up global configurations for Git

This should be done twice, once on the laptop, and later, on the robot.

These options tell Git who you are:

```
$ git config --global user.email "[email]"  
$ git config --global user.name "[full name]"
```

Also do this, and it doesn't matter if you don't know what it is:

```
$ git config --global push.default simple
```

11.4. Git tips

1) Shallow clone

You can clone without history with the command:

```
$ git clone --depth 1 [repository URL]
```

11.5. Git troubleshooting

1) Problem 1: https instead of ssh:

The symptom is:

```
$ git push
Username for 'https://github.com':
```

Diagnosis: the remote is not correct.

If you do `git remote` you get:

```
$ git remote -v
origin https://github.com/duckietown/Software.git (fetch)
origin https://github.com/duckietown/Software.git (push)
```

Solution:

```
$ git remote remove origin
$ git remote add origin git@github.com:duckietown/Software.git
```

Expectation:

```
$ git remote -v
origin git@github.com:duckietown/Software.git (fetch)
origin git@github.com:duckietown/Software.git (push)
```

2) Problem 1: `git push` complains about upstream

The symptom is:

```
fatal: The current branch [branch name] has no upstream branch.
```

Solution:

```
$ git push --set-upstream origin [branch name]
```

CHAPTER 12

Shells

| Assigned to: Andrea

12.1. Byobu

You need to learn to use byobu. It will save much time later.

Byobu is “GNU screen” with fancy configuration; if you know screen, that’s fine as well.

Please learn about Byobu here:

- <http://byobu.co/>

Install using:

```
$ sudo apt install byobu
```

1) Advantages of using Byobu

2) Quick command reference

Quick commands reference, using function keys:

- F2: open a new terminal.
- F3/F4: switch among the terminals.
- Ctrl-F6: close current terminal.

Using control sequences:

- ctrl-A then C: creates new terminal.
- ctrl-A then a number: switches to that terminal.
- ctrl-A then D: detaches the terminal.

To quit a terminal, just use `exit`.

CHAPTER 13

Other things to know

Assigned to: Andrea

13.1. Markdown

PART 3
Preliminaries

CHAPTER 14

Linear algebra

Assigned to: Jacopo

CHAPTER 15

Probability basics

| Assigned to: Liam?



CHAPTER 16

Dynamics

Assigned to: Jacopo

PART 4
Duckiebot setup

CHAPTER 17

Acquiring the parts for the Duckiebot

Assigned to: Jacopo

The trip begins with acquiring the parts. Here, we provide a link to all bits and pieces that are needed to build a Duckiebot.

In general, keep in mind that:

- The links might expire, or the prices might vary.
- In general, substitutions are OK for the mechanical components, and not OK for all the electronics, unless you are OK in writing some software.

Resources necessities:

- Cost: USD ???
- Time: ??? days (average shipping)

Results:

- A kit of parts ready to be assembled.

17.1. Duckiebot configurations

Configuration D17-Ø: Only camera and motors.

Configuration D17-Ø+w: Previous one + an additional WiFi card (Edimax).

Configuration D17-1: LED lights and bumpers

17.2. Bill of materials

Chassis	USD xxx
Camera	USD xxx
Raspberry PI 3	USD 35
Total for minimum configuration	USD ??
Total for fancy configuration	USD ??

17.3. Chassis

We selected the Magician Chassis as the basic chassis for the robot ([Figure 1](#)).

We chose it because it has a double-decker configuration, and so we can put the battery in the lower part.

The price for this in the US is about USD 15-30.



Figure 1. The Magician Chassis

17.4. Raspberry PI 3

...

17.5. Camera

...

CHAPTER 18

Soldering boards

Assigned to: Shiyang

Resources necessities:

- ...
- Time: ??? minutes

Results:

- ...

CHAPTER 19

Assembling the Duckiebot

Assigned to: Shiyong

Resources necessities:

- Duckiebot D17-C0 parts.
 - The acquisition process is explained in [Chapter 17](#).
- Time: about ??? minutes.

Results:

- An assembled Duckiebot in configuration D17-C0.

Shiyong: here will be the instruction about assembling the Duckiebot. :-)

CHAPTER 20

Reproducing the image

Assigned to: Andrea

These are the instructions to reproduce the Ubuntu image that we use.

Please note that the image is already available, so you don't need to do this manually.

However, this documentation might be useful if you would like to port the software to a different distribution.

Resources necessities:

- Internet connection to download the packages.
- A PC running any Linux with an SD card reader.
- Time: about 20 minutes.

Results:

- A baseline Ubuntu Mate 16.04.2 image with updated software.

20.1. Download and uncompress the Ubuntu Mate image

Download the image from the page

<https://ubuntu-mate.org/download/>

The file we are looking for is:

```
filename: ubuntu-mate-16.04.2-desktop-armhf-raspberry-pi.img.xz
size: 1.2 GB
SHA256: dc3afcad68a5de3ba683dc30d2093a3b5b3cd6b2c16c0b5de8d50fede78f75c2
```

After download, run the command `sha256sum` to make sure you have the right version:

```
laptop $ sha256sum ubuntu-mate-16.04.2-desktop-armhf-raspberry-pi.img.xz
dc3afcad68a5de3ba683dc30d2093a3b5b3cd6b2c16c0b5de8d50fede78f75c2
```

If the string does not correspond exactly, your download was corrupted. Delete the file and try again.

Then decompress using the command `xz`:

```
laptop $ xz -d ubuntu-mate-16.04.2-desktop-armhf-raspberry-pi.img.xz
```

20.2. Burn the image to an SD card

Next, burn the image on to the SD card.

→ This procedure is explained in [Section 5.4](#).

1) Verify that the SD card was created correctly

Remove the SD card and plug it in again in the laptop.

Ubuntu will mount two partitions, by the name of `PI_ROOT` and `PI_BOOT`.

2) Installation

Boot the disk in the Raspberry PI.

Choose the following options:

```
language: English
username: ubuntu
password: ubuntu
hostname: duckiebot
```

Choose the option to log in automatically.

Reboot.

3) Update installed software

The WiFi was connected to airport network duckietown with password quackquack.

Afterwards I upgraded all the software preinstalled with these commands:

```
duckiebot $ sudo apt update
duckiebot $ sudo apt dist-upgrade
```

Expect dist-upgrade to take quite a long time (up to 2 hours).

20.3. Raspberry PI Config

The Raspberry PI is not accessible by SSH by default.

Run raspi-config:

```
duckiebot $ sudo raspi-config
```

choose “3. Interfacing Options”, and enable SSH,

We need to enable the camera and the I2C bus.

choose “3. Interfacing Options”, and enable camera, and I2C.

Also disable the graphical boot

20.4. Install packages

Install these packages.

Etckeeper:

```
duckiebot $ sudo apt install etckeeper
```

Editors / shells:

```
duckiebot $ sudo apt install -y vim emacs byobu zsh
```

Git:

```
duckiebot $ sudo apt install -y git git-extras
```

Other:

```
duckiebot $ sudo apt install htop atop nethogs iftop
duckiebot $ sudo apt install aptitude apt-file
```

Development:

```
duckiebot $ sudo apt install -y build-essential libblas-dev liblapack-dev libatlas-base-dev
gfortran libyaml-cpp-dev
```

Python:

```
duckiebot $ sudo apt install -y python-dev ipython python-sklearn python-smbus
duckiebot $ sudo pip install scipy --upgrade
```

I2C:

```
duckiebot $ sudo apt install -y i2c-tools
```

20.5. Install Edimax driver

First, mark the kernel packages as not upgradeable:

```
$ sudo apt-mark hold raspberrypi-kernel raspberrypi-kernel-headers
raspberrypi-kernel set on hold.
raspberrypi-kernel-headers set on hold
```

Then, download and install the Edimax driver from [this repository](#).

20.6. Install ROS

Install ROS.

→ The procedure is given in [Section 40.1](#).

20.7. Wireless configuration (old version)

This is the old version.

There are two files that are important to edit.

The file `/etc/network/interfaces` should look like this:

```
# interfaces(5) file used by ifup(8) and ifdown(8)
# Include files from /etc/network/interfaces.d:
#source-directory /etc/network/interfaces.d

auto wlan0

# The loopback network interface
auto lo
iface lo inet loopback

# Wireless network interface
allow-hotplug wlan0
iface wlan0 inet dhcp
wpa-conf /etc/wpa_supplicant/wpa_supplicant.conf
iface default inet dhcp
```

The file `/etc/wpa_supplicant/wpa_supplicant.conf` should look like this:

```
ctrl_interface=DIR=/var/run/wpa_supplicant GROUP=netdev
update_config=1

network={
    ssid="duckietown"
    psk="quackquack"
    proto=RSN
    key_mgmt=WPA-PSK
    pairwise=CCMP
    auth_alg=OPEN
}
network={
    key_mgmt=NONE
}
```

20.8. Wireless configuration

The files that describe the network configuration are in the directory

```
/etc/NetworkManager/system-connections/
```

This is the contents of the connection file `duckietown`, which describes how to connect to the duckietown wireless network:

```
[connection]
id=duckietown
uuid=e9cef1bd-f6fb-4c5b-93cf-cca837ec35f2
type=wifi
permissions=
secondaries=
timestamp=1502254646

[wifi]
mac-address-blacklist=
mac-address-randomization=0
mode=infrastructure
ssid=duckietown

[wifi-security]
group=
key-mgmt=wpa-psk
pairwise=
proto=
psk=quackquack

[ipv4]
dns-search=
method=auto

[ipv6]
addr-gen-mode=stable-privacy
dns-search=
ip6-privacy=0
method=auto
```

This is the file

```
/etc/NetworkManager/system-connections/create-5ghz-network
```

Contents:


```
[connection]
id=create-5ghz-network
uuid=7331d1e7-2cdf-4047-b426-c170ecc16f51
type=wifi
# Put the Edimax interface name here:
interface-name=[wlx74da38c9caa0 - to change]
permissions=
secondaries=
timestamp=1502023843

[wifi]
band=a
# Put the Edimax MAC address here
mac-address=[74:DA:38:C9:CA:A0 - to change]
mac-address-blacklist=
mac-address-randomization=0
mode=ap
seen-bssids=
ssid=duckiebot-not-configured

[ipv4]
dns-search=
method=shared

[ipv6]
addr-gen-mode=stable-privacy
dns-search=
ip6-privacy=0
method=ignore
```

Note that there is an interface name and MAC address that need to be changed on each PI.

20.9. SSH server config

This enables the SSH server:

```
$ sudo systemctl enable ssh
```

20.10. Create swap Space

Do the following:

Create an empty file using the `dd` (device-to-device copy) command:

```
duckiebot $ sudo dd if=/dev/zero of=/swap0 bs=1M count=512
```

This is for a 512 MB swap space.

Format the file for use as swap:

```
duckiebot $ sudo mkswap /swap0
```

Add the swap file to the system configuration:

```
duckiebot $ sudo vi /etc/fstab
```

Add this line to the bottom:

```
/swap0 swap swap
```

Activate the swap space:

```
duckiebot $ sudo swapon -a
```

20.11. Passwordless sudo

First, make vi the default editor, using

```
sudo update-alternatives --config editor
```

and then choose vim.basic.

Then run:

```
$ sudo visudo
```

And then change this line:

```
%sudo    ALL=(ALL:ALL) ALL
```

into this line:

```
%sudo    ALL=(ALL:ALL) NOPASSWD:ALL
```

20.12. Ubuntu user configuration

1) Groups

You should make the ubuntu user belong to the i2c and input groups:

```
duckiebot $ sudo adduser ubuntu i2c
duckiebot $ sudo adduser ubuntu input
```

: forgot to add to aug20 image:

```
duckiebot $ sudo adduser ubuntu video
```

You may need to do the following (but might be done already through raspi-config):

```
duckiebot $ sudo udevadm trigger
```

2) Basic SSH config

Do the basic SSH config.

→ The procedure is documented in [Section 9.3](#).

Note: this is not in the aug10 image.

3) Passwordless SSH config

Add .authorized_keys so that we can all do passwordless SSH.

The key is at the URL

```
https://www.dropbox.com/s/pxyou3qy1p8m4d0/duckietown_key1.pub?dl=1
```

Download to `.ssh/authorized_keys`:

```
duckiebot $ curl -o .ssh/authorized_keys [URL above]
```

4) Shell prompt

Add the following lines to `~ubuntu/.bashrc`:

```
echo ""  
echo "Welcome to a duckiebot!"  
echo ""  
echo "Reminders:"  
echo ""  
echo "(1) Do not use the user 'ubuntu' for development - create your own user."  
echo "(2) Change the name of the robot from 'duckiebot' to something else."  
echo ""  
  
export EDITOR=vim
```

CHAPTER 21

Installing Ubuntu on laptops

Assigned to: Andrea

Before you prepare the Duckiebot, you need to have a laptop with Ubuntu installed.

Requires:

- A laptop with free disk space.
- Internet connection to download the Ubuntu image.
- About ??? minutes.

Results:

- A laptop ready to be used for Duckietown.

21.1. Install Ubuntu

Install Ubuntu 16.04.2.

→ For instructions, see for example [this online tutorial](#).

On the choice of username: During the installation, create a user for yourself with a username different from `ubuntu`, which is the default. Otherwise, you may get confused later.

21.2. Install useful software

Use `etckeeper` to keep track of the configuration in `/etc`:

```
laptop $ sudo apt install etckeeper
```

Install `ssh` to login remotely and the server:

```
laptop $ sudo apt install ssh
```

Use `byobu`:

```
laptop $ sudo apt install byobu
```

Use `vim`:

```
laptop $ sudo apt install vim
```

Use `htop` to monitor CPU usage:

```
laptop $ sudo apt install htop
```

Additional utilities for `git`:

```
laptop $ sudo apt install git git-extras
```

Other utilities:

```
laptop $ sudo apt install avahi-utils ecryptfs-utils
```

21.3. Install ROS

Install ROS on your laptop.

→ The procedure is given in [Section 40.1](#).

21.4. Other suggested software

1) Redshift

This is Flux for Linux. It is an accessibility/lab safety issue: bright screens damage eyes and perturb sleep [3].

Install redshift and run it.

```
laptop $ sudo apt install redshift-gtk
```

Set to “autostart” from the icon.

2) Installation of the duckuments system

Optional but very encouraged: install the duckuments system. This will allow you to have a local copy of the documentation and easily submit questions and changes.

→ The procedure is documented in [Section 81.4](#).

21.5. Passwordless sudo

Set up passwordless sudo.

→ This procedure is described in [Section 20.11](#).

21.6. SSH and Git setup

1) Basic SSH config

Do the basic SSH config.

→ The procedure is documented in [Section 9.3](#).

2) Create key pair for [username]

Next, create a private/public key pair for the user; call it [username]@[robot name].

→ The procedure is documented in [Section 9.5](#).

3) Add [username]'s public key to Github

Add the public key to your Github account. 

→ The procedure is documented in [Section 22.3](#).

If the step is done correctly, this command should succeed:

```
duckiebot $ ssh -T git@github.com
```

4) Local Git setup

Set up Git locally. 

→ The procedure is described in [Section 11.3](#).

CHAPTER 22

Setup Github access

Assigned to: Andrea

This chapter describes how to create a Github account and setup SSH on the robot and on the laptop.

22.1. Create a Github account

Our example account is the following:

Github name: greta-p
E-mail: greta-p@duckietown.com

Create a Github account ([Figure 2](#)).

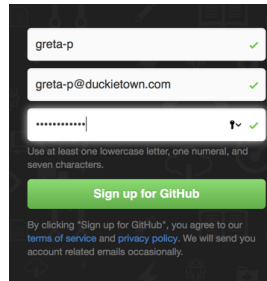
A screenshot of the GitHub sign-up form. It features three input fields: the first contains 'greta-p' with a green checkmark; the second contains 'greta-p@duckietown.com' with a green checkmark; the third is a password field with masked characters and a green checkmark. Below the fields is a green button labeled 'Sign up for GitHub'. A small note below the button states: 'Use at least one lowercase letter, one numeral, and seven characters.' At the bottom, a disclaimer reads: 'By clicking "Sign up for GitHub", you agree to our [terms of service](#) and [privacy policy](#). We will send you account related emails occasionally.'

Figure 2

Go to your inbox and verify the email.

22.2. Become a member of the Duckietown organization

Give the administrators your account name. They will invite you.

Accept the invitation to join the organization that you will find in your email.

22.3. Add a public key to Github

You will do this procedure twice: once for the public key created on the laptop, and later with the public key created on the robot.

Requires:

- A public/private keypair already created and configured.
 - This procedure is explained in [Section 9.5](#).

Result:

- You can access Github using the key provided.

Go to settings ([Figure 3](#)).



Figure 3

Add the public key that you created:



Figure 4



Figure 5



Figure 6

To check that all of this works, use the command

```
$ ssh -T git@github.com
```

The command tries to connect to Github using the private keys that you specified. This is the expected output:

```
Warning: Permanently added the RSA host key for IP address '[ip address]' to the list of known hosts.
Hi [username]! You've successfully authenticated, but GitHub does not provide shell access.
```

If you don't see the greeting, stop.

Repeat what you just did for the Duckiebot on the laptop as well, making sure to change the name of the file containing the private key.

CHAPTER 23

Duckiebot Initialization

Assigned to: Andrea

Prerequisites:

- An SD card of dimensions at least 32 GB.
- A computer with an internet connection, an SD card reader, and 35 GB of free space.
- A mounted Duckiebot in configuration 017-C0.

→ This is the result of [Chapter 19](#).

Result:

- A Duckiebot that is ready to use.

What does it mean “ready to use”?

23.1. Acquire and burn the image

On the laptop, download the compressed image at this URL:

<https://www.dropbox.com/s/1p4am7erdd9e53r/duckiebot-RPI3-AC-aug10.img.xz?dl=1>

The size is 2.5 GB.

You can use:

```
$ curl -o duckiebot-RPI3-AC-aug10.img.xz [URL above]
```

Uncompress the file:

```
$ xz -d -k duckiebot-RPI3-AC-aug10.img.xz
```

This will create a file of 32 GB in size.

To make sure that the image is downloaded correctly, compute its hash using the program sha256sum:

```
$ sha256sum duckiebot-RPI3-AC-aug10.img
2ea79b0fc6353361063c89977417fc5e8fde70611e8afa5cbf2d3a166d57e8cf duckiebot-ac-aug10.img
```

Compare the hash that you obtain with the hash above. If they are different, there was some problem in downloading the image.

Next, burn the image on disk.

→ The procedure of how to burn an image is explained in [Section 5.4](#).

23.2. Turn on the Duckiebot

Put the SD Card in the Duckiebot.

Turn on the Duckiebot by connecting the power cable to the battery.

23.3. Connect the Duckiebot to a network

You can login to the Duckiebot in two ways:

1. Through an Ethernet cable.
2. Through a duckietown WiFi network.

In the worst case, you can use an HDMI monitor and a USB keyboard.

1) Option 1: Ethernet cable

Connect the Duckiebot and your laptop to the same network switch.

Allow 30 s - 1 minute for the DHCP to work.

2) Option 2: Duckietown network

The Duckiebot connects automatically to a 2.4 GHz network called “duckietown” and password “quackquack”.

Connect your laptop to the same wireless network.

23.4. Ping the Duckiebot

To test that the Duckiebot is connected, try to ping it.

The hostname of a freshly-installed duckiebot is `duckiebot-not-configured`:

```
laptop $ ping duckiebot-not-configured.local
```

You should see output similar to the following:

```
PING duckiebot-not-configured.local ([X.X.X.X]): 56 data bytes
64 bytes from [X.X.X.X]: icmp_seq=0 ttl=64 time=2.164 ms
64 bytes from [X.X.X.X]: icmp_seq=1 ttl=64 time=2.303 ms
[...]
```

23.5. SSH to the Duckiebot

Next, try to log in using SSH, with account `ubuntu`:

```
laptop $ ssh ubuntu@duckiebot-not-configured.local
```

The password is `ubuntu`.

By default, the robot boots into `Byobu`.

Please see [Section 12.1](#) for an introduction to `Byobu`.

Not sure it's a good idea to boot into `Byobu`.

23.6. (For D17-C1) Configure the robot-generated network

The Duckiebot in configuration `D17-C0+W` can create a WiFi network.

It is a 5 GHz network; this means that you need to have a 5 GHz WiFi adapter in your laptop.

First, make sure that the Edimax is correctly installed. Using `iwconfig`, you should see four interfaces:

```
$ iwconfig
wlx[AABBCCDDEEFFGG] unassociated Nickname:"rt18822bu"
[...]
lo          no wireless extensions.
enxb827eb1f81a4 no wireless extensions.
wlan1      IEEE 802.11bgn ESSID:"duckietown"
[...]
```

Make note of the name `wlx[AABBCCDDEEFFGG]`.

Look up the MAC address using the command:

```
$ ifconfig wlx[AABBCCDDEEFFGG]
wlx74da38c9caa0 Link encap:Ethernet HWaddr [AA:BB:CC:DD:EE:FF:GG]
```

Then, edit the connection file

```
/etc/NetworkManager/system-connections/create-5ghz-network
```

Make the following changes:

- Where it says `interface-name=[...]`, put `wlx[AABBCCDDEEFFGG]`.
- Where it says `mac-address=[...]`, put `[AA:BB:CC:DD:EE:FF:GG]`.
- Where it says `ssid=duckiebot-not-configured`, put `ssid=[robot name]`.

Reboot.

At this point you should see a new network being created named `"[robot name]"`.

You can connect with the laptop to that network.

If the Raspberry PI's network interface is connected to the `duckietown` network and to the internet, the Raspberry PI will act as a bridge to the internet.

23.7. Setting up wireless network configuration

This part should not be necessary anymore

The Duckiebot is configured by default to connect to a wireless network with SSID `duckietown`. If that is not your SSID then you will need to change the configuration.

You can add a new network by editing the file:

```
/etc/wpa_supplicant/wpa_supplicant.conf
```

You will see a block like the following:

```
network={
  ssid="duckietown"
  scan_ssid=1
  psk="quackquack"
  priority=10
}
```

Add a new one with your SSS and password.

This assumes you have a roughly similar wireless network setup - if not then you might need to change some of the other attributes.

23.8. Update the system

Next, we need to update to bring the system up to date.

Use these commands

```
duckiebot $ sudo apt update
duckiebot $ sudo apt dist-upgrade
```

23.9. Give a name to the Duckiebot

It is now time to give a name to the Duckiebot.

These are the criteria:

- It should be a simple alphabetic string (no numbers or other characters like “-”, “_”, etc.) .
- It will always appear lowercase.
- It cannot be a generic name like “duckiebot”, “robot” or similar.

From here on, we will refer to this string as “[robot name]”. Every time you see [robot name], you should substitute the name that you chose.

23.10. Change the hostname

We will put the robot name in configuration files.

Note: Files in /etc are only writable by root, so you need to use `sudo` to edit them. For example:

```
duckiebot $ sudo vi [filename]
```

Edit the file

```
/etc/hostname
```

and put “[robot name]” instead of `duckiebot-not-configured`.

Also edit the file

```
/etc/hosts
```

and put “[robot name]” where `duckiebot-not-configured` appears.

The first two lines of /etc/hosts should be:

```
127.0.0.1    localhost
127.0.1.1    [robot name]
```

Note: there is a command `hostname` that promises to change the hostname. However, the change given by that command does not persist across reboots. You need to edit the files above for the changes to persist.

Note: Never add other hostnames in /etc/hosts. It is a tempting fix when DNS does not work, but it will cause other problems subsequently.

Then reboot the Raspberry PI using the command

```
$ sudo reboot
```

After reboot, log in again, and run the command `hostname` to check that the change has

persisted:

```
$ hostname  
[robot name]
```

23.11. Create your user

You must not use the `ubuntu` user for development. Instead, you need to create a new user.

Choose a user name, which we will refer to as `[username]`.

To create a new user:

```
duckiebot $ sudo useradd -m [username]
```

Make the user an administrator by adding it to the group `sudo`:

```
duckiebot $ sudo adduser [username] sudo
```

Make the user a member of the group `input` and `i2c`:

```
duckiebot $ sudo adduser [username] input  
duckiebot $ sudo adduser [username] video  
duckiebot $ sudo adduser [username] i2c
```

Set the shell `bash`:

```
duckiebot $ sudo chsh -s /bin/bash andrea
```

To set a password, use:

```
duckiebot $ sudo passwd [username]
```

At this point, you should be able to login to the new user from the laptop using the password:

```
laptop $ ssh [username]@[robot name]
```

Next, you should repeat some steps that we already described.

1) Basic SSH config

Do the basic SSH config.

→ The procedure is documented in [Section 9.3](#).

2) Create key pair for `[username]`

Next, create a private/public key pair for the user; call it `[username]@[robot name]`.

→ The procedure is documented in [Section 9.5](#).

3) Add `[username]`'s public key to Github

Add the public key to your Github account.

→ The procedure is documented in [Section 22.3](#).

If the step is done correctly, this command should succeed:

```
duckiebot $ ssh -T git@github.com
```

4) Local Git configuration

→ This procedure is in [Section 11.3](#).

5) Set up the laptop-Duckiebot connection

Make sure that you can login passwordlessly to your user from the laptop.

→ The procedure is explained in [Section 9.6](#). In this case, we have: `[local]` = laptop, `[local-user]` = your local user on the laptop, `[remote]` = `[robot name]`, `[remote-user]` = `[username]`.

If the step is done correctly, you should be able to login from the laptop to the robot, without typing a password:

```
laptop $ ssh [username]@[robot name]
```

6) Some advice on the importance of passwordless access

In general, if you find yourself:

- typing an IP
- typing a password
- typing `ssh` more than once
- using a screen / USB keyboard

it means you should learn more about Linux and networks, and you are setting yourself up for failure.

Yes, you “can do without”, but with an additional 30 seconds of your time. The 30 seconds you are not saving every time are the difference between being productive roboticists and going crazy.

Really, it is impossible to do robotics when you have to think about IPs and passwords...

23.12. Other customizations

If you know what you are doing, you are welcome to install and use additional shells, but please keep Bash as be the default shell. This is important for ROS installation.

For the record, our favorite shell is ZSH with `oh-my-zsh`.

23.13. Hardware check: camera

Check that the camera is connected using this command:

```
duckiebot $ vcgencmd get_camera
supported=1 detected=1
```

If you see `detected=0`, it means that the hardware connection is not working.

You can test the camera right away using a command-line utility called `raspistill`.

Use the `raspistill` command to capture the file `out.jpg`:

```
duckiebot $ raspistill -t 1 -o out.jpg
```

Then download `out.jpg` to your computer using `scp` for inspection.

→ For instructions on how to use `scp`, see [Subsection 9.8.1](#).

1) Troubleshooting

Symptom: `detected=0`

Resolution: If you see `detected=0`, it is likely that the camera is not connected correctly.

If you see an error that starts like this:

```
mmal: Cannot read camera info, keeping the defaults for 0V5647
[...]
mmal: Camera is not detected. Please check carefully the camera module is installed correctly.
```

then, just like it says: “Please check carefully the camera module is installed correctly.”.

CHAPTER 24

Software setup and RC remote control

Assigned to: Andrea

Prerequisites:

- You have configured the laptop.
 - The procedure is documented in [Chapter 21](#).
- You have configured the Duckiebot.
 - The procedure is documented in [Chapter 23](#).
- You have created a Github account and configured public keys, both for the laptop and for the Duckiebot.
 - The procedure is documented in [Chapter 22](#).

Results:

- You can run the joystick demo.

24.1. Clone the Duckietown repository

All of the following should be

Clone the repository in the directory ~/duckietown:

```
duckiebot $ git clone git@github.com:duckietown/Software.git ~/duckietown
```

For the above to succeed you should have a Github account already set up.

It should not ask for a password.

1) Troubleshooting

Symptom: It asks for a password.

Resolution: You missed some of the steps described in [Chapter 22](#).

Symptom: Other weird errors.

Resolution: Probably the time is not set up correctly. Use `ntpdate` as above:

```
$ sudo ntpdate -u us.pool.ntp.org
```

24.2. Set up ROS environment on the Duckiebot

All the following commands should be run in the ~/duckietown directory:

```
duckiebot $ cd ~/duckietown
```

Now we are ready to make the workspace. First you need to source the baseline ROS environment:


```
duckiebot $ source /opt/ros/kinetic/setup.bash
```

Then, build the workspace using:

```
duckiebot $ catkin_make -C catkin_ws/
```

* *for more information about `catkin_make`, see [Subsection 40.5.3](#).*

AC: I had to run it twice. The first time it complained:

```
In file included from /home/andrea/duckietown/catkin_ws/src/apriltags_ros/apriltags_ros/src/
apriltag_detector.cpp:1:0:
/home/andrea/duckietown/catkin_ws/src/apriltags_ros/apriltags_ros/include/apriltags_ros/
apriltag_detector.h:6:41: fatal error: duckietown_msgs/BoolStamped.h: No such file or directory
```

24.3. Add your vehicle to the machines file

On the robot edit the file

```
~/duckietown/catkin_ws/src/duckietown/machines
```

You will see something like this:

```
<launch>
  <arg name="env_script_path" default="~/duckietown/environment.sh"/>

  <machine name="[robot name]" address="[robot name].local" user="[username]"
env-loader="$(arg env_script_path)"/>
  ...
  ...
</launch>
```

Now, duplicate a `<machine>` line between `<launch>` and `</launch>`, and replace the name and address string with the name of your vehicle.

For example, for Andrea, `[robot name]` = emma and `[username]` = andrea. So, he would add this line:

```
<machine name="emma" address="emma.local" user="andrea" env-loader="$(arg env_script_path)"/>
```

Commit and push the new machines file. (No, don't commit the machines file.)

24.4. Test that the joystick is detected

Make sure that your user is in the group `input` and `i2c`:

```
duckiebot $ groups
[username] sudo input i2c
```

If `input` and `i2c` are not in the list, you missed a step. Ohi ohi! You are not following the instructions carefully!

→ Consult again [Section 23.11](#).

Plug the joystick receiver in one of the USB port on the Raspberry PI.

To make sure that the joystick is detected, run:

```
duckiebot $ ls /dev/input/
```

and check if there is a device called `js0` on the list.

To test whether or not the joystick itself is working properly, run:

```
duckiebot $ jstest /dev/input/js0
```

Move the joysticks and push the buttons. You should see the data displayed change according to your actions.

24.5. Run the joystick demo

SSH into the Raspberry PI and run the following from the `duckietown` directory:

```
duckiebot $ cd ~/duckietown
duckiebot $ source environment.sh
```

The `environment.sh` setups the ROS environment at the terminal (so you can use commands like `roslaunch` and `roslaunch`).

Now make sure the motor shield is connected.

Run the command:

```
duckiebot $ roslaunch duckietown joystick.launch veh:=[robot name]
```

If there is no “red” output in the command line then pushing the left joystick knob controls throttle - right controls steering.

This is the expected result of the commands:

left joystick up	forward
left joystick down	backward
right joystick left	turn left (positive theta)
right joystick right	turn right (negative theta)

It is possible you will have to unplug and replug the joystick or just push lots of buttons on your joystick until it wakes up. Also make sure that the mode switch on the top of your joystick is set to “X”, not “D”.

Is all of the above valid with the new joystick?

Close the program using Ctrl-C.

1) Troubleshooting

Symptom: The robot moves weirdly (e.g. forward instead of backward).

Resolution: The cables are not correctly inserted. Please refer to the assembly guide for pictures of the correct connections. Try swapping cables until you obtain the expected behavior.

Resolution: Check that the joystick has the switch set to the position “x”. And the mode light should be off.

Symptom: The left joystick does not work.

Resolution: If the green light on the right to the “mode” button is on, click the “mode” button to turn the light off. The “mode” button toggles between left joystick or the cross on the left.

Symptom: The robot does not move at all.

Resolution: The cables are disconnected.

Resolution: The program assumes that the joystick is at `/dev/input/js0`. In doubt, see [Section 24.4](#).

24.6. The proper shutdown procedure for the Raspberry PI

Generally speaking, you can terminate any `roslaunch` command with `Ctrl-C`.

To completely shutdown the robot, issue the following command:

```
duckiebot $ sudo shutdown -h now
```

Then wait 30 seconds.

Warning If you disconnect the power before shutting down properly using `shutdown`, the system might get corrupted.

Then, disconnect the power cable, at the **battery end**.

Warning If you disconnect frequently the cable at the Raspberry PI's end, you might damage the port.

CHAPTER 25

Reading from the camera

Prerequisites:

- You have configured the Duckiebot.
→ The procedure is documented in [Chapter 23](#).
- You know the basics of ROS (launch files, roslaunch, topics, rostopic).

Results:

- You know that the camera works under ROS.

25.1. Check the camera hardware

It might be useful to do a quick camera hardware check.

- The procedure is documented in [Section 23.13](#).

25.2. Create two windows

On the laptop, create two Byobu windows.

- A quick reference about Byobu commands is in [Section 12.1](#).

You will use the two windows as follows:

- In the first window, you will launch the nodes that control the camera.
- In the second window, you will launch programs to monitor the data flow.

Note: You could also use multiple *terminals* instead of one terminal with multiple Byobu windows. However, using Byobu is the best practice to learn.

25.3. First window: launch the camera nodes

In the first window, we will launch the nodes that control the camera.

Activate ROS:

```
duckiebot $ source environment.sh
```

Run the launch file called `camera.launch`:

```
duckiebot $ roslaunch duckietown camera.launch veh:=[robot name]
```

At this point, you should see the red LED on the camera light up continuously.

In the terminal you should not see any red message, but only happy messages like the following:

```
[...]
[INFO] [1502539383.948237]: [/[robot name]/camera_node] Initialized.
[INFO] [1502539383.951123]: [/[robot name]/camera_node] Start capturing.
[INFO] [1502539384.040615]: [/[robot name]/camera_node] Published the first image.
```

* For more information about *roslaunch* and “launch files”, see [Section 40.3](#).

25.4. Second window: view published topics

Switch to the second window.

Activate the ROS environment:

```
duckiebot $ source environment.sh
```

1) List topics

You can see a list of published topics with the command:

```
duckiebot $ rostopic list
```

* For more information about *rostopic*, see [Section 40.5](#).

You should see the following topics:

```
/[robot name]/camera_node/camera_info
/[robot name]/camera_node/image/compressed
/[robot name]/camera_node/image/raw
/rosout
/rosout_agg
```

2) Show topics frequency

You can use *rostopic hz* to see the statistics about the publishing frequency:

```
laptop $ rostopic hz /[robot name]/camera_node/image/compressed
```

On a Raspberry PI 3, you should see a number close to 30 Hz:

```
average rate: 30.016
min: 0.026s max: 0.045s std dev: 0.00190s window: 841
```

3) Show topics data

You can view the messages in real time with the command *rostopic echo*:

```
laptop $ rostopic echo /[robot name]/camera_node/image/compressed
```

You should see a large sequence of numbers being printed to your terminal.

That’s the “image” — as seen by a machine.

If you are Neo, then this already makes sense.

If you are not Neo, use *Ctrl-C* to stop *rostopic*.

Later, in [Chapter 27](#), you will learn how to visualize the image stream on the laptop using *rviz*.

CHAPTER 26

RC control launched remotely

Assigned to: Andrea

Prerequisites:

- You can run the joystick demo from the Raspberry PI.
 - The procedure is documented in [Chapter 24](#).

Results:

- You can run the joystick demo from your laptop.

26.1. Two ways to launch a program

ROS nodes can be launched in two ways:

1. “local launch”: log in to the Raspberry PI using SSH and run the program from there.
2. “remote launch”: run the program directly from a laptop.

Which is better when is a long discussion that will be done later. Here we set up the “remote launch”.

26.2. Make sure that you can log in from the laptop

Make sure that you can login with SSH *without a password*. From the laptop, run:

```
laptop $ ssh [username]@[robot name].local
```

If this doesn't work, you missed some previous steps.

26.3. Download and setup Software repository on the laptop

As you did on the Duckiebot, you should clone the Software repository in the `~/duckietown` directory.

- The procedure is documented in [Section 24.1](#).

Then, you should build the repository.

- This procedure is documented in [Section 24.2](#).

26.4. Edit the machines files on your laptop

You have to edit the machines files on your laptop, as you did on the Duckiebot.

- The procedure is documented in [Section 24.3](#).

26.5. Start the demo

Now you are ready to launch the joystick demo remotely.

Run this *on the laptop*:

```
laptop $ source environment.sh
laptop $ roslaunch duckietown joystick.launch veh:=[robot name]
```

You should be able to drive the vehicle with joystick just like the last example. Note that remotely launching nodes from your laptop doesn't mean that the nodes are running on your laptop. They are still running on the Raspberry PI in this case.

* For more information about *roslaunch*, see [Section 40.3](#).

26.6. Watch the program output using `rqt_console`

Also, you might have notice that the terminal where you launch the launch file is not printing all the printouts like the previous example. This is one of the limitation of remote launch.

Don't worry though, we can still see the printouts using `rqt_console`.

On the laptop, open a new terminal window, and run:

```
laptop $ export ROS_MASTER_URI=http://[robot name].local:11311/
laptop $ rqt_console
```

AC: I could not see any messages in `rqt_console` - not sure what is wrong.

You should see a nice interface listing all the printouts in real time, completed with filters that can help you find that message you are looking for in a sea of messages.

You can use `Ctrl-C` at the terminal where *roslaunch* was executed to stop all the nodes launched by the launch file.

* For more information about *rqt_console*, see [Section 40.2](#).

26.7. Troubleshooting

Symptom: *roslaunch* fails with an error similar to the following:

```
remote[robot name].local-0]: failed to launch on [robot name]:
Unable to establish ssh connection to [[username]@[robot name].local:22]:
Server u'[robot name].local' not found in known_hosts.
```

Resolution: You have not followed the instructions that told you to add the `HostKeyAlgorithms` option. Delete `~/.ssh/known_hosts` and fix your configuration.

→ The procedure is documented in [Section 9.3](#).

CHAPTER 27

RC+camera remotely

Assigned to: Andrea

Prerequisites:

- You can run the joystick demo remotely.
 - The procedure is documented in [Chapter 26](#).
- You can read the camera data from ROS.
 - The procedure is documented in [Chapter 25](#).
- You know how to get around in Byobu.
 - You can find the Byobu tutorial in [Section 12.1](#).

Results:

- You can run the joystick demo from your laptop and see the camera image on the laptop.

27.1. Assumptions

We are assuming that the joystick demo in [Chapter 26](#) worked.

We are assuming that the procedure in [Chapter 25](#) succeeded.

We also assume that you terminated all instances of `roslaunch` with `Ctrl-C`, so that currently there is nothing running in any window.

27.2. Terminal setup

On the laptop, this time create **four** Byobu windows.

- A quick reference about Byobu commands is in [Section 12.1](#).

You will use the four windows as follows:

- In the first window, you will run the joystick demo, as before.
- In the second window, you will launch the nodes that control the camera.
- In the third window, you will launch programs to monitor the data flow.
- In the fourth window, you will use `rviz` to see the camera image.

27.3. First window: launch the joystick demo

In the first window, launch the joystick remotely using the same procedure in [Section 26.5](#).

```
laptop $ source environment.sh
laptop $ roslaunch duckietown joystick.launch veh:=[robot name]
```


You should be able to drive the robot with the joystick at this point.

27.4. Second window: launch the camera nodes

In the second window, we will launch the nodes that control the camera.

The launch file is called `camera.launch`:

```
laptop $ source environment.sh
laptop $ roslaunch duckietown camera.launch veh:=[robot name]
```

You should see the red led on the camera light up.

27.5. Third window: view data flow

Open a third terminal on the laptop.

You can see a list of topics currently on the ROS_MASTER with the commands:

```
laptop $ source environment.sh
laptop $ export ROS_MASTER_URI=http://[robot name].local:11311/
laptop $ rostopic list
```

You should see the following:

```
/diagnostics
/[robot name]/camera_node/camera_info
/[robot name]/camera_node/image/compressed
/[robot name]/camera_node/image/raw
/[robot name]/joy
/[robot name]/wheels_driver_node/wheels_cmd
/rosout
/rosout_agg
```

27.6. Fourth window: visualize the image using `rviz`

Launch `rviz` by using these commands:

```
laptop $ source environment.sh
laptop $ source set_ros_master.sh [robot name]
laptop $ rviz
```

* For more information about `rviz`, see [Section 40.4](#).

In the `rviz` interface, click “Add” on the lower left, then the “By topic” tag, then select the “Image” topic by the name

```
/[robot name]/camera_node/image/compressed
```

Then click “ok”. You should be able to see a live stream of the image from the camera.

27.7. Proper shutdown procedure

To stop the nodes: You can stop the node by pressing `Ctrl-C` on the terminal where `roslaunch` was executed. In this case, you can use `Ctrl-C` in the terminal where you launched the `camera.launch`.

You should see the red light on the camera turn off in a few seconds.

Note that the `joystick.launch` is still up and running, so you can still drive the vehicle with the joystick.

CHAPTER 28

Interlude: Ergonomics

Assigned to: Andrea

So far, we have been spelling out all commands for you, to make sure that you understand what is going on.

Now, we will tell you about some shortcuts that you can use to save some time.

Note: in the future you will have to debug problems, and these problems might be harder to understand if you rely blindly on the shortcuts.

Results:

- You will know about some useful shortcuts.

28.1. set_ros_master.sh

Instead of using:

```
$ export ROS_MASTER_URI=http://[robot name].local:11311/
```

You can use the “set_ros_master.sh” script in the repo:

```
$ source set_ros_master.sh [robot name]
```

Note that you need to use `source`; without that, it will not work.

28.2. SSH aliases

Instead of using

```
$ ssh [username]@[robot name].local
```

You can set up SSH so that you can use:

```
$ ssh my-robot
```

To do this, create a host section in `~/.ssh/config` with the following contents:

```
Host my-robot
  User [username]
  Hostname [robot name].local
```

Here, you can choose any other string in place of “my-robot”.

Note that you **cannot** do

```
$ ping my-robot
```

You haven’t created another hostname, just an alias for SSH.

However, you can use the alias with all the tools that rely on SSH, including `rsync` and `scp`.

CHAPTER 29

Wheel calibration

| Assigned to: Andrea

CHAPTER 30

Camera calibration

CHAPTER 31

Taking a log

| Assigned to: Andrea

CHAPTER 32

D17-1 (LEDs) parts

Assigned to: Jacopo

CHAPTER 33
D17-1 (LEDs) assembly

| Assigned to: Shiyong

CHAPTER 34

D17-1 (LEDs) setup

Assigned to: Andrea

PART 5
Duckietowns

CHAPTER 35

Duckietown parts

Assigned to: Jacopo

CHAPTER 36

Duckietown Assembly

| Assigned to: Shiyong

CHAPTER 37

The Duckietown specification

| Assigned to: Liam?

37.1. Topology

1) Topology constraints

37.2. Signs placement

CHAPTER 38

Traffic lights

PART 6

Developing software

This part is about how to develop software for the Duckiebot.

CHAPTER 39

Python

39.1. Background reading

- Python
- Python tutorial

39.2. Python virtual environments

Install using:

```
$ sudo apt install virtualenv
```

39.3. Useful libraries

```
matplotlib  
seaborn  
numpy  
panda  
scipy  
opencv  
...
```


CHAPTER 40

Introduction to ROS

Assigned to: Liam

40.1. Install ROS

This part installs ROS. You will run this twice, once on the laptop, once on the robot.

The first commands are copied from [this page](#).

Tell Ubuntu where to find ROS:

```
$ sudo sh -c 'echo "deb http://packages.ros.org/ros/ubuntu $(lsb_release -sc) main" > /etc/apt/sources.list.d/ros-latest.list'
```

Tell Ubuntu that you trust the ROS people (they are nice folks):

```
$ sudo apt-key adv --keyserver hkp://ha.pool.sks-keyservers.net:80 --recv-key 421C365BD9FF1F717815A3895523BAEED01FA116
```

Fetch the ROS repo:

```
$ sudo apt update
```

Now install the mega-package `ros-kinetic-desktop-full`.

```
$ sudo apt install ros-kinetic-desktop-full
```

There's more to install:

```
$ sudo apt install ros-kinetic-{tf-conversions,cv-bridge,image-transport,camera-info-manager,theora-image-transport,joy,image-transport}
```

Note: Do not install packages by the name of `ros-X`, only those by the name of `ros-kinetic-X`. The packages `ros-X` are from another version of ROS.

: not done in aug20 image:

Initialize ROS:

```
$ sudo rosdep init
$ rosdep update
```

40.2. `rqt_console`

40.3. `roslaunch`

40.4. `rviz`

40.5. rostopic

1) rostopic hz

2) rostopic echo

3) catkin_make

4) Troubleshooting

Symptom: [computer] is not in your SSH known_hosts file

See [this thread](#). Remove the known_hosts file and make sure you have followed the instructions in [Section 9.3](#).

CHAPTER 41

What the duck!

what-the-duck is a program that tests *dozens* of configuration inconsistencies that can happen on a Duckiebot.

To use it, first compile the repository, and then run:

```
$ ./what-the-duck
```

41.1. Adding more tests to what-the-duck

The idea is to add to what-the-duck all the tests that can be automated.

The documentation about to do that is not ready yet.

The current tests are available in the file:

```
./catkin_ws/src/f23-LED/led_detection/include/what_the_duck/list_of_checks.py
```

41.2. Tests already added

Here's the list of tests already added:

```
✓ Camera is detected
✓ Scipy is installed
✓ sklearn is installed
✓ Date is set correctly
✓ Not running as root
✓ Not running as ubuntu
✓ Member of group sudo
✓ Member of group input
✓ Member of group video
✓ Member of group i2c
✓ ~/.ssh exists
✓ ~/.ssh permissions
✓ ~/.ssh/config exists
✓ SSH option HostKeyAlgorithms is set
✓ At least one key is configured.
✓ ~/.ssh/authorized_keys exists
✓ Git configured
✓ Git email set
✓ Git name set
✓ Git push policy set
✓ Edimax detected
✓ The hostname is configured
✓ /etc/hosts is sane
✓ Correct kernel version
✓ Messages are compiled
✓ Shell is bash
✓ Working internet connection
✓ Github configured
✓ Joystick detected
✓ Environment variable DUCKIETOWN_ROOT
✓ ${DUCKIETOWN_ROOT} exists
✓ Wifi network configured
```

41.3. List of tests to add

Please add below any configuration test that can be automated:

- Check that all the `rosX` command resolve to a file `/opt/ros/kinetic/bin/rosX`.
- Make sure that packages such as `python-roslaunch` are not installed. (The user is invited to install it when `roslaunch` is not found!)

CHAPTER 42

How to create a ROS package

42.1. Conforming ROS package checklist

- ☐ The name of the package is package_[\[handle\]](#)
- ☐ The directory is in ...
- ☐ The messages are called
- ☐ there is a readme file
- ☐ there is the first launch file

CHAPTER 43

Integrate package in the architecture

CHAPTER 44
Creating unit tests

PART 7

Modules

These are the learning modules.

CHAPTER 45

Module template

Assigned to: Jacopo

CHAPTER 46

Autonomy overview

| Assigned to: Liam

46.1. Perception, planning, control

CHAPTER 47

Autonomy architectures

Assigned to: Andrea

CHAPTER 48

Representations

| Assigned to: Matt

CHAPTER 49

Software architectures and middlewares

Assigned to: Andrea

CHAPTER 50

Modern signal processing

| Assigned to: Andrea

CHAPTER 51

Basic Kinematics

Assigned to: Jacopo

CHAPTER 52

Basic Dynamics

| Assigned to: Jacopo

CHAPTER 53

Odometry Calibration

Assigned to: Jacopo

CHAPTER 54

Computer vision basics

| Assigned to: Matt



CHAPTER 55

Illumination invariance

Assigned to: Matt

CHAPTER 56

Line Detection

| Assigned to: Matt

CHAPTER 57

Feature extraction

Assigned to: Matt

CHAPTER 58

Place recognition

| Assigned to: Matt

CHAPTER 59

Filtering 1

Assigned to: Liam

CHAPTER 60

Filtering 2

| Assigned to: Liam

CHAPTER 61

Mission planning

Assigned to: ETH

CHAPTER 62

Planning in discrete domains

Assigned to: ETH

CHAPTER 63

Motion planning

Assigned to: ETH

CHAPTER 64

RRT

| Assigned to: ETH

CHAPTER 65

Feedback control

Assigned to: Jacopo

CHAPTER 66

PID Control

| Assigned to: Jacopo

CHAPTER 67

MPC Control

Assigned to: Jacopo

CHAPTER 68

Object detection

| Assigned to: Nick and David

CHAPTER 69

Object classification

Assigned to: Nick and David

CHAPTER 70

Object tracking

| Assigned to: Nick and David

CHAPTER 71

Reacting to obstacles

Assigned to: Jacopo

CHAPTER 72

Semantic segmentation

| Assigned to: Nick and David

CHAPTER 73

Text recognition

Assigned to: Nick

CHAPTER 74

SLAM - Problem formulation

| Assigned to: Liam

CHAPTER 75

SLAM - Broad categories

Assigned to: Liam

CHAPTER 76

VINS

| Assigned to: Liam

CHAPTER 77

Advanced place recognition

Assigned to: Liam

CHAPTER 78

Fleet level planning (placeholder)

| Assigned to: ETH

CHAPTER 79

Fleet level planning (placeholder)

Assigned to: ETH

PART 8

How to contribute

CHAPTER 80

Accounts

80.1. Complete list of accounts

Currently, Duckietown has the following accounts:

- Github: for source code, and issue tracking;
- Slack: a forum for wide communication;
- Twist: to be used for instructors coordination;
- Google Drive: to be used for instructors coordination, maintaining TODOs, etc;
- Dropbox Folders (part of Andrea's personal accounts): to be abandoned;
- Vimeo, for storing the videos;
- The `duckietown-teaching` mailing list, for low-rate communication with instructors;
- We also have a list of addresses, of people signed up on the website, that we didn't use yet;
- The Facebook page.

80.2. For Fall 2017

As a student in Fall 2017, these are the accounts that you need:

- A Github account and membership in the Duckietown organization.
- A Slack account, for team discussion and organization.

As an instructor/TA for the Fall 2017 class, in addition to the accounts above, these are the accounts that you need:

- Twist: for class organization (such as TAs, logistics);
- Google Docs, used to maintain TODOs.

80.3. For other contributors

If you are an international contributor:

- Sign up on Slack, to keep up with the project.
- (optional) Get Github permissions if you do frequent updates to the repositories.

CHAPTER 81

Contributing to the documentation

81.1. Where the documentation is

All the documentation is in the repository `duckietown/duckuments`.

The documentation is written as a series of small files in Markdown format.

It is then processed by a series of scripts to create this output:

- [a publication-quality PDF](#);
- [an online HTML version, split in multiple pages and with comments boxes](#).

81.2. Editing links

The simplest way to contribute to the documentation is to click any of the “✎” icons next to the headers.

They link to the “edit” page in Github. There, one can make and commit the edits in only a few seconds.

81.3. Comments

In the multiple-page version, each page also includes a comment box powered by a service called Disqus. This provides a way for people to write comments with a very low barrier. (We would periodically remove the comments.)

81.4. Installing dependencies for compiling the documentation

Let `DUCKUMENTS` be the base directory for the documentation.

Download the `duckuments` repo in that directory:

```
$ git clone git@github.com:duckietown/duckuments.git $DUCKUMENTS
```

Cd into directory:

```
$ cd $DUCKUMENTS
```

1) Setup a virtual environment

On Ubuntu 16.04, create a virtual environment usign `virtualenv` (`sudo apt install virtualenv` if needed):

```
$ virtualenv --system-site-packages deploy
```

In other distributions you might need to use `venv`:

```
$ venv deploy
```

Activate the virtual environment:

```
$ source $DUCKUMENTS/deploy/bin/activate
```

Install some dependencies:

```
$ sudo apt install libxml2-dev libxslt1-dev
$ sudo apt install libffi6 libffi-dev
$ sudo apt install python-dev python-numpy python-matplotlib
```

Clone the mcdp external repository:

```
$ cd $DUCKUMENTS
$ git clone -b duckuments git@github.com:AndreaCensi/mcdp.git
```

Install it and its dependencies:

```
$ cd $DUCKUMENTS/mcdp
$ python setup.py develop
```

(If you get a permission error here, it means you have not properly activated the virtualenv)

Depending on your system, you might need to install these other dependencies: (It should not be necessary on Ubuntu 16 given the apt commands above.)

```
$ cd $DUCKUMENTS
$ pip install numpy matplotlib
```

81.5. Extra dependencies for compiling the PDF version

Note: The dependencies below are harder to install. If you don't manage to do it,⁸ then you only lose the ability to compile the PDF. You can do `make compile` to compile the HTML version, but you cannot do `make compile-pdf`.

Ensure the latest version (>6) of nodejs is installed.

Run:

```
$ nodejs --version
6.xx
```

If the version is 4 or less, remove nodejs:

```
$ sudo apt remove nodejs
```

Install nodejs using [the instructions at this page](#).

Next, install the necessary Javascript libraries using npm:

```
$ cd $DUCKUMENTS
$ npm install MathJax-node jsdom@9.3 less
```

Install PrinceXML from [this page](#).

Download STIX fonts from [this site](#).

Unzip and copy the ttf to ~/.fonts:

```
$ cp -R STIXv2.0.0 ~/.fonts
```

and then rebuild the font cache using:

```
$ fc-cache -fv
```

81.6. Troubleshooting installation problems

1) Installing `nodejs` packages

The only pain point in the installation procedure has been the installation of `nodejs` packages using `npm`. For some reason, they cannot be installed globally (`npm install -g`). Do not use `sudo` for installation. It will cause problems.

If you use `sudo`, you probably have to delete a bunch of directories, such as: `RBR00T/node_modules`, `~/.npm`, and `~/.node_modules`, if they exist.

81.7. Compiling the documentation

Make sure you have deployed and activated the virtual environment. Then:

```
$ cd $DUCKUMENTS
$ make duckuments-dist
```

This creates the directory `duckuments-dist`, which contains another checked out copy of the repository, but with the branch `gh-pages`, which is the branch that is published by Github using the “Github Pages” mechanism.

At this point, please make sure that you have these two `.git` folders:

```
$DUCKUMENTS/.git
$DUCKUMENTS/duckuments-dist/.git
```

To compile the docs, go in the `DUCKUMENTS` directory and run `make compile`:

```
$ cd $DUCKUMENTS
$ make clean compile
```

To see the result, open the file

```
./duckuments-dist/master/duckiebook/index.html
```

1) Incremental compilation

If you want to do incremental compilation, you can omit the `clean` and just use:

```
$ make compile
```

This will be faster. However, sometimes it might get confused. At that point, do `make clean`.

2) Compiling the PDF

To compile the PDF, use:

```
$ make compile-pdf
```

This creates the file:


```
./duckuments-dist/master/duckiebook.pdf
```

81.8. Deploying the documentation

This part is now done by a bot, so you don't need to do it manually.

To deploy the documentation, jump into the `DUCKUMENTS/duckuments-dist` directory.

Run the command `git branch`. If the out does not say that you are on the branch `gh-pages`, then one of the steps before was done incorrectly.

```
$ cd $DUCKUMENTS/duckuments-dist
$ git branch
...
* gh-pages
...
```

Now, after triple checking that you are in the `gh-pages` branch, you can use `git status` to see the files that were added or modified, and simply use `git add`, `git commit` and `git push` to push the files to Github.

81.9. In summary: the workflow

This is the workflow:

1. Edit the Markdown in the `master` branch of the `duckuments` repository.
2. Run `make compile` to make sure it compiles.
3. Commit the Markdown and push on the `master` branch.

Done. The bot will redo the compilation and push the changes in the `gh-pages` branch.

Step 2 is done, so you know that the bot will not encounter errors.

Features of the documentation writing system

The Duckiebook is written in a Markdown dialect. A subset of LaTeX is supported. There are also some additional features that make it possible to create publication-worthy materials.

82.1. Embedded LaTeX

You can use ***LaTeX*** math, environment, and references. For example, take a look at

$$x^2 = \int_0^t f(\tau) \, d\tau$$

or refer to [Proposition 1](#).

Proposition 1. (Proposition example) This is an example proposition: $2x = x + x$.

The above was written as in [Figure 7](#).

```
You can use  $\LaTeX$  math, environment, and references.
For example, take a look at

\[\begin{aligned} x^2 &= \int_0^t f(\tau) \, d\tau \end{aligned}\]

or refer to \[Proposition example\].

\begin{proposition}[Proposition example]\label{prop:example}
This is an example proposition:  $2x = x + x$ .
\end{proposition}
```

Figure 7. Use of LaTeX code.

82.2. Other interesting features

Make sure to quote (with 4 spaces) all command lines. Otherwise, the dollar symbol confuses the LaTeX interpreter.

1) Shortcut for tables

The shortcuts col2, col3, col4, col5 are expanded in tables with 2, 3, 4 or 5 columns.

```
<div make-col2="">
  <span>A</span>
  <span>B</span>
  <span>C</span>
  <span>D</span>
</div>
```

2) Creating figures

For any element, adding an attribute called figure-id with contents fig:[figure ID](#) or tab:[table ID](#) will create a figure that wraps the element.

For example:

```
<p figure-id="fig:code">
  I will be the content of a figure.
</p>
```

It will create HTML of the form:

```
<div id='fig:code-wrap' class='generated-figure-wrap'>
  <figure id='fig:code' class='generated-figure'>
    <p figure-id='fig:code'>
      I will be the content of a figure.
    </p>
  </figure>
</div>
```

To add a class to the figure, use `figure-class`:

```
<element figure-id="fig:code" figure-class="myclass">
  content
</element>
```

This will give it to the `<figure>` and the containing `<figure>`

To add a caption, add an attribute `figure-caption`:

```
<element figure-id="fig:code" figure-caption="This is my caption">
  content
</element>
```

Alternatively, you can put anywhere an element `figcaption` with ID `[figure id]:caption`:

```
<element figure-id="fig:code">
  content
</element>

<figcaption id='fig:code:caption'>
  This is my caption. Can contain <code>code</code>.
</figcaption>
```

82.3. Character escapes

Use the string `$` to write the dollar symbol `$`, otherwise it gets confused with LaTeX[®] math materials. Also notice that you should probably use “USD” to refer to U.S. dollars

Other symbols to escape:

- use ``` instead of ```
- use `$` instead of `$`
- use `<` instead of `<`
- use `>` instead of `>`

82.4. Troubleshooting

Symptom: “Invalid XML”

Resolution: “Markdown” doesn’t mean that you can put anything in a file. Except for the code blocks, it must be valid XML. For example, if you use “>” and “<” without quoting, it will likely cause a compile error.

Symptom: “Tabs are evil”

Resolution: Do not use tab characters. The error message in this case is quite helpful in telling you exactly where the tabs are.

| Symptom: The error message contains `ValueError: Suspicious math fragment '\LaTeX'`

Resolution: You probably have forgotten to indent a command line by at least 4 spaces. The dollar in the command line is now being confused for a math formula.

CHAPTER 83

Documentation style guide

This chapter describes the conventions for writing the technical documentation.

83.1. General guidelines for technical writing

The following holds for all technical writing.

- The documentation is written in correct English.
- Do not say “should” when you mean “must”. “Must” and “should” have precise meanings and they are not interchangeable. These meanings are explained [in this document](#).
- “Please” is unnecessary in technical documentation.
 - ✗ “Please remove the SD card.”
 - ✓ “Remove the SD card”.
- Do not use colloquialisms or abbreviations.
 - ✗ “The pwd is ubuntu.”
 - ✓ “The password is ubuntu.”
- Do not use emojis.
- Do not use ALL CAPS.
- Make infrequent use of **bold statements**.
- Do not use exclamation points.

83.2. Style guide for the Duckietown documentation

- It’s ok to use “it’s” instead of “it is”, “can’t” instead of “cannot”, etc.
- All the filenames and commands must be enclosed in code blocks using Markdown backticks.
 - ✗ “Edit the ~/.ssh/config file using vi.”
 - ✓ “Edit the `~/.ssh/config` file using `vi`.”
- `Ctrl-C`, `ssh` etc. are not verbs.
 - ✗ “Ctrl-C from the command line”.
 - ✓ “Use `Ctrl-C` from the command line”.
- Subtle humor and puns about duckies are encouraged.

83.3. Writing command lines

Use either “laptop” or “duckiebot” (not capitalized, as a hostname) as the prefix for the command line.

For example, for a command that is supposed to run on the laptop, use:

```
laptop $ cd ~/duckietown
```

For a command that must run on the Duckiebot, use:

```
duckiebot $ cd ~/duckietown
```

If the command is supposed to be run on both, omit the hostname:

```
$ cd ~/duckietown
```

83.4. Frequently misspelled words

- “Duckiebot” is always capitalized.
- Use “Raspberry PI”, not “PI”, “raspi”, etc.
- These are other words frequently misspelled: 5 GHz WiFi

83.5. Other conventions

When the user must edit a file, just say: “edit `/this/file`”.

Writing down the command line for editing, like the following:

```
$ vi /this/file
```

is too much detail.

(If people need to be told how to edit a file, Duckietown is too advanced for them.)

83.6. Troubleshooting sections

Write the documentation as if every step succeeds.

Then, at the end, make a “Troubleshooting” section.

Organize the troubleshooting section as a list of symptom/resolution.

The following is an example of a troubleshooting section.

1) Troubleshooting

Symptom: This strange thing happens.

Resolution: Maybe the camera is not inserted correctly. Remove and reconnect.

Symptom: This other strange thing happens.

Resolution: Maybe the plumbus is not working correctly. Try reformatting the plumbus.

PART 9

Fall 2017

This is the first time that a class is taught jointly across 3 continents!

There are 4 universities involved in the joint teaching for the term:

- ETH Zürich (ETHZ), with instructors Emilio Frazzoli, Andrea Censi, Jacopo Tani.
- University of Montreal (UdeM), with instructor Liam Paull.
- TTI Chicago (TTI), with instructor Matthew Walter.
- National C T University (NCTU), with instructor Nick Wang.

This part of the Duckiebook describes all the information that is needed by the students of the four institutions.

CHAPTER 84

General remarks

| Assigned to: Andrea

84.1. The rules of Duckietown

The first rule of Duckietown

The first rule of Duckietown is: you don't talk about Duckietown, *using email*.

Instead, we use a communication platform called Slack.

There is one exception: inquiries about “meta” level issues, such as course enrollment and other official bureaucratic issues can be communicated via email.

The second rule of Duckietown

The second rule of Duckietown is: be kind and respectful, and have fun.

The third rule of Duckietown

The third rule of Duckietown is: read the instructions carefully.

Do not blindly copy and paste.

Only run a command if you know what it does.

84.2. Synchronization between classes

At ETHZ, UdeM, TTIC, the class will be more-or-less synchronized. The materials are the same; there is some slight variation in the ordering.

Moreover, there will be some common groups for the projects.

The NCTU class is undergraduate level. Students will learn slightly simplified materials. They will not collaborate directly with the classes.

84.3. Accounts for students

To participate in Duckietown, students must use two accounts: Slack and Github.

1) Slack

2) Github

84.4. Accounts for all instructors and TAs

There are two more accounts required for instructors and TAs

1) Twist

TODO:

2) Google docs

TODO:

In particular:

- This is the schedule: ...
- This is the calendar in which to annotate everything: ...

84.5. Other accounts for organizers

1) Duckietown-teaching

84.6. Additional information for ETH Zürich students

| Assigned to: Andrea

This section describes information specific for ETH Zürich students.

1) Website

| All really important information, such as deadlines, is in the authoritative website:

2) Duckiebox distribution

3) Lab access

4) The local TAs

84.7. Additional information for UdeM students

| Assigned to: Liam

84.8. Additional information for TTIC students

| Assigned to: Matt

84.9. Additional information for NCTU students

| Assigned to: Nick

CHAPTER 85

Project proposals

CHAPTER 86
Template of a project

PART 10

Fall 2017 student progression

CHAPTER 87

Milestone: ROS node working

CHAPTER 88

Homework: Take and process a log

CHAPTER 89

Milestone: Calibrated robot

CHAPTER 90
Homework: Camera geometry

CHAPTER 91

Milestone: Illumination invariance

CHAPTER 92

Homework: Place recognition

CHAPTER 93

Milestone: Lane following

CHAPTER 94

Homework: localization

CHAPTER 95

Milestone: Navigation

CHAPTER 96

Homework: group forming

CHAPTER 97

Milestone: Ducks in a row

CHAPTER 98

Homework: Comparison of PID

CHAPTER 99

Homework: RRT

CHAPTER 100

Caffe tutorial

CHAPTER 101

Milestone: Object Detection

CHAPTER 102

Homework: Object Detection

CHAPTER 103

Milestone: Semantic perception

CHAPTER 104

Homework: Semantic perception

CHAPTER 105

Milestone: Reacting to obstacles

CHAPTER 106

Homework: Reacting to obstacles

CHAPTER 107

Milestone: SLAM demo

CHAPTER 108

Homework: SLAM

CHAPTER 109

Milestone: fleet demo

CHAPTER 110

Homework: fleet

110.1. Checklist for students

- Have a Github account. See [Chapter 22](#). See name conventions (TODO).
- Be part of the Duckietown Github organization. You are sure only when you commit and push one change to one of our repositories.
- Be part of the Duckietown Slack. See name conventions (TODO).

110.2. Checklist for TAs

- Be signed up on

CHAPTER 111

Bibliography

- [1] Jacopo Tani, Liam Paull, Maria Zuber, Daniela Rus, Jonathan How, John Leonard, and Andrea Censi. **Duckietown: an innovative way to teach autonomy**. In *EduRobotics 2016*. Athens, Greece, December 2016.  pdf
- [2] Liam Paull, Jacopo Tani, Heejin Ahn, Javier Alonso-Mora, Luca Carlone, Michal Cap, Yu Fan Chen, Changhyun Choi, Jeff Dusek, Daniel Hoehener, Shih-Yuan Liu, Michael Novitzky, Igor Franzoni Okuyama, Jason Pazis, Guy Rosman, Valerio Varricchio, Hsueh-Cheng Wang, Dmitry Yershov, Hang Zhao, Michael Benjamin, Christopher Carr, Maria Zuber, Sertac Karaman, Emilio Frazzoli, Domitilla Del Vecchio, Daniela Rus, Jonathan How, John Leonard, and Andrea Censi. **Duckietown: an open, inexpensive and flexible platform for autonomy education and research**. In *IEEE International Conference on Robotics and Automation (ICRA)*. Singapore, May 2017.  pdf
- [3] Tosini, G., Ferguson, I., Tsubota, K. *Effects of blue light on the circadian system and eye physiology*. *Molecular Vision*, 22, 61–72, 2016 ([online](#)).

PART 11

Drafts or pieces to remove

CHAPTER 112

Laptop setup

112.1. Setup passwordless SSH to log in using the `ubuntu` user

On each Duckiebot it is possible to log in as the `ubuntu` user using a common key.

Now, let's set up passwordless SSH, so that you don't need to type a password.

On the laptop, create the `.ssh` directory:

```
laptop $ mkdir -p ~/.ssh
```

The key `duckietown_key1` is found at the URL:

```
https://www.dropbox.com/s/q23qptu01u7ur3y/duckietown_key1?dl=1
```

Download the file and call it `~/.ssh/duckietown_key1`

```
laptop $ curl -o ~/.ssh/duckietown_key1 [URL above]
```

Edit the permission of the file. SSH wants the key file to be not readable or writable from other users or groups.

```
laptop $ chmod 600 ~/.ssh/duckietown_key1
```

Regenerate the public key according to:

```
laptop $ ssh-keygen -f ~/.ssh/duckietown_key1 -y > ~/.ssh/duckietown_key1.pub
```

On the laptop, now edit `~/.ssh/config` and add the following lines:

```
Host [robot name]
  Hostname [robot name].local
  User [user name]
  IdentityFile ~/.ssh/duckietown_key1
  HostKeyAlgorithms ssh-rsa
```

Now you should be able to connect without using a password.

The following command should connect without a password being asked:

```
laptop $ ssh ubuntu@[robot name]
```

1) Troubleshooting

Symptom: “Scheme missing”

Resolution: If there are issues such as “scheme missing” and the file `duckietown_key1` does not exist in the `~/.ssh/` folder, but instead downloaded a file named `duckietown_key1?dl=1` in the current folder, simply rename `duckietown_key1?dl=1` to `duckietown_key1` and copy it over to the directory `~/.ssh/`.